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Building Innovation-System Builders for Biofuels in Developing Countries: Lessons from Developed Nations

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ABSTRACT:

This thesis examines the possibility of developing an innovation system builder for biofuels in a resource constrained country based on knowledge gained from a more developed national system. The study is inspired by a nagging transition problem. In many developing economies, biomass resources are available and policy interest has been expressed, however, biofuel activity has been fragmented and pilot oriented. Stable innovation trajectories, institutional co-ordination and market formation have therefore not been realised.

The objective of the thesis is to identify key system functions; organisational capabilities; governance arrangements supporting biofuel system-building and to assess how these may be modified to Nepal. The National Innovation System perspective, the triple helix and the climate relevant Innovation-system Builder perspective are informing the study. The concepts of absorptive capacity and institutional distance are used to make sense of the scope and limits of policy learning and functional transfer across contexts.

A comparative qualitative case study approach is used. Finland and Nepal are used as the two national cases and VTT Technical Research Centre of Finland and Nepal Academy of Science and Technology as focal organisational cases in them. The empirical material is taken from policy documents, organisational records, sectoral and agency reports as well as peer-reviewed academic literature. The material has been analysed using deductive coding based on the conceptual framework created in the thesis.

It is found that The Finnish biofuel system has been underpinned by coordinated policy direction, oil common pilot and test infrastructure, applied research capacity, and credible standards and verification capabilities. These functions have been strengthened by relatively stable institutions, and by ordinary interaction between government, research organisations and industry actors. In the Nepalese case, there is both technical knowledge and policy interest, but poor institutional linkages between research, testing, piloting and standardisation, and the formation of a market. Coordination has been patchy, testing and verification capacity has been limited and pilot activity has yet to be integrated into stable routines for learning.

It is concluded that the lesson-drawing in biofuel transitions should be based on functional adaptation and not direct organisational copying. For Nepal the central task is not the replication of the Finnish institutional model, but the piecemeal building up of a smaller set of system functions in accordance with local constraints. A phased roadmap is therefore proposed in which coordination capacity and a minimum standards pathway are established first followed by the progressive establishment of pilot nodes, learning loops and broader market support functions. The thesis makes a function-first interpretation of the biofuel system-building and provides practical implications for policy, research and industry in Nepal.

KEYWORDS: innovation-system builder, biofuels, comparative case study, Finland, Nepal, policy transfer

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List Of Abbreviations

Abbreviation	Full form
AC	Absorptive capacity
AD	Anno Domini (Gregorian calendar year)
AEPC	Alternative Energy Promotion Centre
ATF	Aviation Turbine Fuel
CRIB	Climate-Relevant Innovation-system Builder
EEA	European Environment Agency
FY	Fiscal Year
IEA	International Energy Agency
ISB	Innovation-system builder
kL	Kilolitre
LPG	Liquefied Petroleum Gas
MLP	Multi-Level Perspective
MoU	Memorandum of Understanding
MRQ	Main research question
MT	Metric tonnes
NAST	Nepal Academy of Science and Technology
NDC	Nationally Determined Contribution
NIS	National Innovation System
NIS/TIS	National Innovation System / Technological Innovation System
NOC	Nepal Oil Corporation
OECD	Organisation for Economic Co-operation and Development
PRO	Public research organisation
R&D	Research and development
RTO	Research and Technology Organisation
TH	Triple Helix
VTT	Technical Research Centre of Finland
WTO	World Trade Organization

1 Introduction

1.1 Background: energy transition and the biofuels in developing countries puzzle

Energy systems are being reorganised under two pressures that do not always align. First, economies are expected to decarbonise fast enough to limit climate risks. Second, they must supply reliable and affordable energy to households and firms, while supporting industrial activity and trade competitiveness. This is why “energy transition” is not merely an environmental agenda. It is an economic transformation problem that depends on investment, organisational capability, and institutional coordination (Geels, 2002; Markard et al., 2012; International Energy Agency (IEA), 2024).

Despite the rapid growth of clean energy, the world's energy economy still relies heavily on fossil fuels. Recent evidence indicates that a significant proportion of incremental energy demand is still met from oil, gas and coal with high emissions from energy-related activities (IEA, 2024). The implication is not that the transition is failing - in absolute terms, that is. The point is that transition pathways are determined by history and conflict. Existing infrastructure is important. Incumbent interests matter. Policy swings matter. Change therefore proceeds in the form of a socio-technical process with co-evolving technology, regulation, finance and legitimacy in society (Geels, 2002; Sovacool, 2016).

Developing countries are facing this transformation under tighter constraints. Many are continuing to provide access to energy and manage rapid urban growth. At the same time, they want to bring up-to-date industrial capacity. These goals are juxtaposed with thin capital markets, weaker research infrastructure, and low capacity to implement them in the state. So things that look good on paper often are difficult to scale in practice.

The underlying problem is that innovation is not just produced by individual firms or entrepreneurs. It is also a system property. Outcomes depend on the extent to which actors connect to each other, whether learning is cumulative and whether governance creates enough certainty for investment to take place (Lundvall, 2010; Hekkert et al., 2007). In this framing, the "puzzle" of energy transition in developing countries is often a puzzle of institutional capability, not only of technology.

Biofuels occupy a strategic yet disputed role in this larger issue. They are not a panacea. Yet they are still relevant for at least three reasons. First, they can help mitigate exposure to imported petroleum in segments where electrification may be slow due to cost, infrastructure requirements or fleet composition (IEA, 2024). Second, they can also support rural development by creating markets for residues and bio-mass-based value chains which can link transition goals with local income generation (Farrell et al., 2006). Third, they can facilitate industrial upgrading if policy and innovation systems facilitate domestic learning processes in feedstock management, conversion pro-cesses, quality standards and blending logistics (Malerba, 2002; Hekkert et al., 2007).

At the same time, there are legitimacy constraints on the biofuels, which are boundary conditions for any scale-up strategy. The food vs. fuel conflict is not a theoretical concern. Large-scale expansion can amplify pressures on land and water resources, influence food prices, and result in indirect land use change emissions when production displaces the existing uses (Searchinger et al., 2008; Fargione et al., 2008). Sustainability outcomes are dependent on feedstock choice, land governance, enforcement capacity and traceability systems. Even low-input pathways of apparent ones still require credible governance to avoid environmental damage and social backlash (Tilman et al., 2006). For developing countries, the scaling up of biofuels therefore is not just a production challenge. It is also an issue of governance.

This highlights a pragmatic institutional void. Many developing countries possess biomass resources and policy ambition, but have problems developing stable innovation trajectories. The missing element is often the ability to coordinate actors, organise learning, to set standards, broker partnerships and reduce perceived risk for investors. These are system functions. They do not often appear by accident. They are typically carried out by institutions that are located between research, government and industry.

This thesis addresses that institutional gap as the overriding business and policy issue. The important question is not just what to build in terms of technology. It is how a country can build organisational capability to organise biofuel innovation at scale, and this with sustainability legitimacy.

There are several pillars in the literature that may help in solving the above-defined challenge. The first pillar is the National Innovation System (NIS) perspective. It considers innovation as an interaction between firms, universities, research organisations and actors of public policy (Lundvall, 2010; Freeman, 1987). This is of importance because it diverts the attention from isolated projects and focuses on conditions within the system such as coordination, stable expectations, and cumulative learning.

The second pillar is the "builder" lens. This lens focuses on organisations that consciously bear system functions, especially in cases where the markets do not generate coordination by themselves. Innovation intermediaries can broker networks, translate knowledge across communities and decrease uncertainty for investors and policymakers (Howells, 2006; Klerkx & Leeuwis, 2009). Public research and technology organisations (RTO) can also serving as institutional carriers of applied knowledge production and demonstration capacity particularly in sectors where infrastructure and standards are influential in diffusion (Suvinen et al., 2010; Loikkanen et al., 2011). This links in with Triple Helix (TH) theory which highlights co-evolution and collaboration between universities, industry and government as a factor in innovation performance (Etzkowitz & Leydesdorff, 2000).

The third pillar is institutional learning and lessons drawing. Policy transfer research claims that learning from abroad is seldom a question of copying. It is selective, political conditioned and influenced by institutional distance (Dolowitz & Marsh, 2000). For Nepal, the implication is direct. Lessons from Finland do need to be translated into functions and routines that work within local constraints rather than into institutional templates.

Developed country institutions cannot be imported into the emerging market system like a ready solution. A credible learning approach has to establish what functions are transferable, which ones need to be redesigned and which ones rely on local capacity building.

Conceptually, the thesis also draws on the Climate-Relevant Innovation-system Builder (CRIB) idea proposed in the climate and development literature. CRIB places emphasis on institutions that enable low-carbon innovation in developing countries through capability building, network formation, and alignment between policy goals and technological learning (Ockwell & Byrne, 2016). Using CRIB alongside NIS and TH strengthens the

analytical focus on the organisational and governance functions needed to build a biofuel sector in a constrained context.

1.2 Research context: Finland as a developed innovation system and Nepal as a context of capability building

This study is based on a comparative learning design. Finland is considered as a mature innovation system in which bioenergy and associated technologies have been advanced by a long-term policy support, good applied research capabilities and stable coordination institutions. Nepal is explored as a capacity-building situation where energy security issues are coupled with low depth of industrial base and research infrastructure, where biofuel initiatives have had to fail time and again to get beyond the pilot stage.

Finland's bioenergy trajectory is useful as it combines resource endowments with intentional institution building. Recent national reporting shows that a high share of renewables in gross final energy consumption is maintained in Finland with bioenergy playing a central role in the renewable mix (Pelkmans & Hiltunen, 2024). Sectoral differences still matter. Renewable shares in heating and cooling, electricity and transport reflect different policy instruments and technology pathways such as bioenergy integration in combined heat and power systems and blending in transport fuels (Pelkmans & Hiltunen, 2024). This is important for developing countries as it indicates that the transition results depend on governance and industrial structure, and not solely on the availability of resources.

A special feature of the Finnish case is the existence of coordination institutions, which are located between science, industry and government. The Technical Research Centre of Finland (VTT) is widely recognised as a research and technology organisation, which supports applied research, industrial collaboration, piloting and demonstrations. Work on innovation intermediaries and public research organisations (PRO) suggests that such bodies are able to address system failures by brokering networks, supporting knowledge transfer, commercialisation, and strengthening credibility for emerging technologies

(Howells, 2006; Suvinen et al., 2010; Loikkanen et al., 2011). In bioenergy, in which supply chains, quality standards and infrastructure interfaces determine viability, these intermediary functions can be decisive.

Nepal is a very different setting. The country still relies on import of petroleum products and this makes the economy vulnerable to price fluctuations and supply disruptions, as well as maintaining pressure on the import bill (Sharma & Shrestha, 2023). Nepal also has a large renewable potential, most notably hydropower; and the country has experience of modern deployments of bioenergy, most notably household and community-scale biogas and biomass-based solutions. Yet the transition from disparate projects to an integrated biofuel industry is limited. Reviews of Nepal's modern bioenergy options repeatedly call for disjointed institutional responsibilities, poor linkages between research and commercial players, weak capacity for standardisation and testing, and uneven policy follow-through (Gurung & Oh, 2013; Silveira & Khatiwada, 2010).

Biofuel interest in Nepal has frequently been cast in the context of energy security with biodiesel paths being explored. Early feasibility work on Jatropha biodiesel, for example, addressed it as a potential response to dependency on diesel imports and to rural development objectives, but identified constraints in agronomy, supply logistics and institutional sup-port (Timilsina & Tiwari, 2015). Renewable energy agencies such as the Alternative Energy Promotion Centre (AEPC) have promoted the deployment of renewable energies and the implementation of policies but those mandates do not necessarily result in a system-building capability for biofuels. Biofuels need coordinated efforts between ministries, re-search bodies, private companies and regulators on a sustained basis (AEPC, 2021).

Within this context, the Nepal Academy of Science and Technology (NAST) is used as a focal candidate for innovation-system building role. The contention is not that NAST can bring about sector transformation on its own. It is that NAST offers a concrete organisational locus for the assessment of system-building functions, such as the ability to broker collaboration, strengthen absorptive capacity and support standard-setting and demonstration.

1.3 Research Gap and Problem statement

The practical problem is that biofuel initiatives in Nepal have not led to a long life of investment which has been durable. Pilots and proposals are available, but scale-up has been limited by breakdowns in co-ordination and poor institutional linkages. Responsibilities are dispersed among several bodies Research capacity is still limited and is often isolated from commercial application. Testing, certification and quality standards are not yet well developed. These gaps increase transaction costs, undermine credibility and discourage private investment in supply chains.

The analytical problem is that many things that have been said to explain existing events are not specific enough for design. A vast body of work has been documented on the common constraints in the innovation systems of developing countries: weak research infrastructure; fragmented institutions; low technological learning; and lack of government-industry-university linkages (Arocena & Sutz, 2010; Bell & Pavitt, 1993). These diagnoses are important but actually often stop short of specifying how missing coordination capacity can be deliberately con-structed. The literature seems to describe what is missing. It provides less information on how system-building capability can be developed under institutional constraint.

The key to this argument is absorptive capacity. Absorptive capacity is the capacity of an organisation to recognise, assimilate and apply external knowledge (Cohen & Levinthal, 1990). In developing country transitions, the weak absorptive capacity is a limiting factor to technology transfer and policy borrowing. Imported technologies and copied instruments can be a poor fit unless domestic institutions are able to adapt these technologies, reliably operate them, and learn from early instances of failure. This implies that system-building organisations need to do more than provide funds for projects. They must actively create learning capabilities, networks and governance routines that keep innovation trajectories moving.

The problem addressed in this thesis is therefore framed as a capability-building question: *how can a developing country build an effective innovation-system builder (ISB) for biofuels that performs coordination and learning functions, while maintaining sustainability legitimacy*.

Finland provides an empirical setting where system-building functions are visible through the operation of mature intermediaries and research organisations, with VTT as a focal example. Nepal provides a setting where the weakness of such functions constrains scaling, with NAST as a focal organisation for analysing institutional gaps and feasible design moves.

The research gap lies in the difference between diagnosis and design. Existing literature explains many of the constraints that weaken innovation systems in developing countries, including fragmented mandates, weak research-industry linkages, low technological learning, and poor absorptive capacity. What remains less clearly specified is how a system-building organisation can be deliberately designed to address these weaknesses in a climate-relevant sector such as biofuels. The gap is therefore not only empirical but also practical. It concerns how coordination, learning, piloting, standards support, and legitimacy functions can be organised in a resource-constrained setting. This thesis addresses that gap by comparing a mature reference context with an emerging one and by translating lessons at the level of functions rather than institutional form.

1.4 Research aim and research questions

The aim of this thesis is *to develop a structured account of how an ISB for the biofuel sector can be designed in a developing country by drawing lessons from a developed-country model*. The study operationalises this logic through a Finland-to-Nepal comparison, with VTT and NAST serving as focal organisations.

The thesis is guided by one main research question and two bounded sub-questions.

Main research question (MRQ)

How can a developing country build an effective ISB for the biofuel sector by drawing lessons from a developed-country model?

Sub-question 1 (Finland within-case)

What functions, capabilities, and governance arrangements enable Finland's ISBs, with emphasis on VTT, to support biofuel innovation?

Sub-question 2 (Nepal within-case and design implication)

What institutional and capability gaps limit Nepal's potential ISB, with emphasis on NAST, and what lessons are transferable given Nepal's constraints?

This thesis uses a comparative qualitative case study design. Finland and Nepal are examined as contrasting national contexts, and VTT Technical Research Centre of Finland and Nepal Academy of Science and Technology are treated as focal organisational cases within them. The study relies on document-based evidence, including policy documents, organisational records, sector reports, and peer-reviewed research. The material is analysed through deductive coding derived from the conceptual framework developed in the literature review. This design is used to identify system-building functions, compare how they are carried in the two contexts, and assess what lessons can be adapted from Finland to Nepal under conditions of institutional distance and absorptive capacity constraint.

1.5 Scope, delimitations, and key definitions

The ***scope*** of this thesis is the innovation system surrounding biofuels and adjacent bioenergy innovation functions. The emphasis is on institutions and organisational capabilities that enable research, demonstration, standardisation, and market formation for biofuel-related technologies. The thesis does not attempt to evaluate the entire energy system of either country, and it does not provide a full life-cycle assessment of specific fuels.

This study examines the institutional environment, coordination arrangements, and organisational functions that shape biofuel innovation. It does not evaluate individual policy instruments one by one, estimate project-level techno-economics, or assess environmental impacts through fuel-specific life-cycle or land-use modelling.

Three delimitations follow. First, the *Finland-to-Nepal comparison is analytical*. It is designed to extract transferable design principles rather than to recommend one-to-one replication. Second, *the empirical focus is on two focal organisations*, VTT and NAST, as carriers of system-building functions. This does not imply that innovation depends on single actors. It reflects a methodological choice to examine system functions through identifiable institutional anchors. Third, the *thesis treats sustainability governance as a*

necessary condition for biofuel legitimacy. Therefore, “scaling” is not defined as volume growth alone. It includes the credibility of standards, monitoring, and public acceptance.

Key definitions are introduced here and used consistently.

National Innovation System (NIS) refers to the set of institutions and actors whose interactions shape the creation, diffusion, and use of new knowledge within a country (Lundvall, 2010).

Innovation-system builder (ISB) refers to an organisation that deliberately performs coordination and capability-building functions that strengthen an innovation system, especially under conditions of fragmentation.

Climate-Relevant Innovation-system Builder (CRIB) refers to an ISB focused on enabling low-carbon innovation in developing countries through functions such as capability building, network formation, and policy-technology alignment (Ockwell & Byrne, 2016).

Triple Helix (TH) refers to the co-evolutionary interactions among universities, industry, and government that shape innovation processes and institutional change (Etzkowitz & Leydesdorff, 2000).

1.6 Structure of the thesis

Chapter 2 reviews the literature on energy transitions, innovation systems, intermediaries, and ISBs, and it develops the conceptual framework guiding the study. Chapter 3 outlines the research design, including case selection, data sources, and analytical approach. Chapter 4 presents the Finland case with emphasis on VTT and the institutional conditions supporting biofuel innovation. Chapter 5 analyses the Nepal case, focusing on NAST, institutional gaps, and feasibility constraints. Chapter 6 synthesises findings across the two cases, derives transferable lessons, and proposes design implications for building an ISB for biofuels in Nepal. Chapter 7 concludes the thesis and outlines practical and research implications.

2 Literature Review

This chapter develops the theoretical foundations for analysing how biofuel sectors can be strengthened in developing countries through purposeful innovation-system building. The review proceeds in seven steps. First, it positions energy transitions as socio-technical change processes and explains why innovation systems are central to transition outcomes. Second, it introduces the National Innovation System **(**NIS) perspective and contrasts the structural properties of NIS in developed and developing contexts. Third, it explains the Triple Helix (TH) logic and argues why dedicated boundary-spanning organisations are often needed to translate TH interactions into coordinated innovation. Fourth, it reviews technology transfer and lesson-drawing scholarship and highlights how institutional distance and absorptive capacity shape what can be learned and implemented. Fifth, it presents the Climate-Relevant Innovation-system Builder **(**CRIB) framework as a functional lens for organisations that build sectoral capability in late-industrialising contexts. Sixth, it integrates these strands into a conceptual framework suitable for a Finland to Nepal comparison, with emphasis on VTT Technical Research Centre of Finland (VTT) and Nepal Academy of Science and Technology (NAST). Finally, it concludes with a set of analytical propositions that guide subsequent empirical analysis. The study is **positioned** at the intersection of innovation systems theory, institutional learning, and sustainability transitions research. The National Innovation System perspective is used to explain how institutions, incentives, and learning structures shape sector development. The Triple Helix perspective is used to clarify why university–industry–government interaction often requires intermediating organisations that can reduce coordination costs and stabilise collaboration. The Climate-Relevant Innovation-system Builder perspective is then used to specify the functions required in developing-country contexts, especially in sectors where capability-building, legitimacy, and policy alignment are central. This **theoretical positioning** supports the thesis aim of analysing biofuel system-building as an organisational and institutional design problem rather than only as a technology adoption issue.

2.1 Energy transitions and innovation systems

2.1.1 Defining energy transitions

Energy transitions refer to long-run shifts in how societies produce, distribute, and consume energy, involving changes in technologies, infrastructure, markets, regulations, and user practices. The definitional point is important because it prevents an overly narrow view of transitions as a simple substitution of fuels or equipment. Instead, transitions reconfigure interdependent systems. They alter industrial structures, reshape value chains, create new skills demands, and change the legitimacy conditions under which policy and investment become feasible (Geels, 2002; Markard, Raven and Truffer, 2012).
A socio-technical frame is extensively used to make sense of this complexity. In the Multi-Level Perspective (MLP), transitions are understood in terms of interaction between innovations in the niches, the incumbent socio-technical regimes and pressures in the broader landscape (Geels, 2002; Geels and Schot, 2007). Niche spaces are spaces of experimentation and early learning. Regimes are stabilising dominant technologies and institutions. Landscape dynamics are used to capture wider pressures such as geopolitics, demographic change and climate commitments.
From a Multi-Level Perspective (MLP) reading, policy and institutions are not on the periphery. They influence the transition itself. Progress hinges on the ability of niche experiments to mature and bridge niche markets, the capacity of incumbent regimes to adapt without impeding change and the development of landscape pressures into domestic political coalitions that maintain reform (Geels, 2002; Valkenburg and Cotella, 2016).
In biofuels, socio-technical complexity is compounded by politics of feedstocks and land use implications. The sector is at the intersection of the energy security, rural development and decarbonisation. Yet its legitimacy remains conditional as biofuel expansion can trigger concerns around issues of food security, land conversion, biodiversity loss and indi-rect emissions. Sustainability controversies, therefore, function as institutional con-straints. They affect what is considered a path that is acceptable and whether or not in-vestment is socially and politically durable over time (Searchinger et al., 2008; Fargione et al., 2008).

2.1.2 Structural barriers to energy transition in the developing countries

Energy transitions in developing countries are faced with structural barriers, which are of a different type and intensity compared to those in high-income economies. Four constraints are repeated in the literature. First, investment constraints are systemic. High capital costs, lack of domestic finance and high perceived risk limit experimentation and scaling at early stages. Second, there are infrastructure bottlenecks, which limit learning-by-doing. Weak logistic net-works, unreliable power supply and limited quality standards limit the ability of firms to iterate and upgrade. Third, there is policy instability which raises uncertainty and weakens credibility. Short policy cycles, frequent shifts in tariff and subsidy regimes and fragmented responsibilities make investors nervous. Fourth, poor innovation capability limits adaptation. Firms and public agencies may not have the skills, routines, and or-ganisational capacity to absorb the external knowledge and turn it into locally workable solutions. Low research and development (R&D) intensity and limited pool of specialised human resources and weak linkages between research organisations and industry lead to low speed of technology localisation and improvement of imported technologies (Arocena and Sutz, 2000; Bell and Pavitt, 1993; Intarakumnerd, Chairatana and Tangchitpiboon, 2002).These constraints motivate a shift from “technology choice” thinking to “capability-building” thinking. This is precisely where innovation systems scholarship becomes useful. It emphasises learning, networks, institutions, and the coordination of complementary investments (Freeman, 1987; Lundvall, 1992; Nelson, 1993).

Biofuels are strategically relevant in this setting, but they are also institutionally demanding. Successful biofuel development requires stable sustainability rules, credible quality standards, supply chain coordination from feedstock to conversion to distribution, and iterative learning in production and use. These requirements are difficult to meet when organisational mandates are fragmented and when there is no strong intermediary that can align actors and investments. Innovation-system building is a core explanatory lens. **Table 1** consolidates the conceptual lenses used in this thesis to interpret energy transitions and explains why each lens matters for biofuel sector development.

Table 1. Conceptual lenses for analysing energy transitions and why they matter for biofuels

Lens	Core focus	What it highlights for biofuels
Sustainability transitions (MLP)	Regime change and socio-technical alignment	Legitimacy, coalition building, and institutional fit
Innovation systems (NIS/TIS)	Learning, networks, institutions, and functions	Coordination failures, missing linkages, and capability gaps
Political economy of biofuels	Distributional effects and contested land use	Sustainability governance, food-fuel tensions, and policy durability

***Note**. Synthesis derived from established transition and innovation-systems lenses. The table draws on the Multi-Level Perspective within sustainability transitions research and on NIS and Technological Innovation System thinking, while the political economy lens reflects distributional and land-use governance debates central to biofuels (Geels, 2002; Markard, Raven, & Truffer, 2012; Searchinger et al., 2008).*

For example, in Nepal, the transition challenge is often framed by three intersecting conditions. First, energy security concerns are shaped by import dependence for petroleum fuels. Second, rural development priorities create sustained interest in bio-based value chains that could support livelihoods and reduce vulnerability. Third, constraints in institutional capacity limit the conversion of policy intent into stable market formation and coordinated innovation. These conditions make Nepal a suitable setting for examining how system-building capability can be deliberately designed rather than assumed.

2.2 National Innovation System (NIS): developed vs developing countries

2.2.1 Definition and foundations of NIS

The concept of a NIS refers to the set of institutions, organisations, and interactions that shape the creation, diffusion, and use of economically useful knowledge within a national boundary (Freeman, 1987; Lundvall, 1992; Nelson, 1993). The core claim is not that innovation is confined within borders. The claim is that national institutions structure incentives, shape learning patterns, and condition how global knowledge flows are absorbed and transformed.

A defining feature of NIS scholarship is its critique of purely market-centred accounts. Conventional economic approaches often assume firms respond efficiently to price signals. NIS perspectives argue instead that innovation depends on interactive learning and institutional complementarities. Firms, universities, PROs, standards agencies, and financing institutions jointly shape innovation performance. When coordination is weak, innovation becomes uneven and path dependent (Edquist, 1997; Freeman, 1987).

Analytically, a NIS can be read as a coordination and learning architecture. It operates through (i) knowledge production and diffusion, (ii) human capital formation, (iii) governance of research agendas, and (iv) institutional rules that shape experimentation and selection.

2.2.2 NIS in developing countries

Developing-country NIS often display structural weaknesses that are not simply gaps relative to OECD benchmarks (OECD, 2015). They reflect distinct historical trajectories and political economy constraints. Three features are frequently emphasised. First, research infrastructures tend to be thin and unevenly connected to production sectors. Public research may exist, but incentives often reward publications or donor-driven projects rather than industry-coupled problem solving. Second, organisational mandates are frequently fragmented. Responsibilities for energy, agriculture, environment, and industry policy can be dispersed across agencies with limited coordination capacity. Third, learning is constrained by low technological accumulation and weak industrial upgrading pathways. Firms frequently operate far from the frontier, and upgrading depends on incremental learning that requires stable support structures (Bell and Pavitt, 1993; Arocena and Sutz, 2000).

These characteristics explain why the same policy instruments may work differently across contexts. For example, generic R&D tax incentives presume a baseline level of firm capability and absorptive capacity. In low-capability environments, the binding constraint may be the absence of intermediaries that can translate research into production routines, help firms articulate demand for knowledge, and coordinate shared infrastructure. **Table 2** contrasts developed and developing innovation-system conditions and draws out what those differences imply for the design of system-building organisations.

Table 2 Stylised contrasts between developed and developing NIS and implications for system building organisations

Dimension	Developed NIS (stylised)	Developing NIS (stylised)	Implication for an ISB
Institutional coherence	Higher policy stability and clearer mandates	Fragmented mandates, policy volatility	ISB must actively broker alignment and continuity
Research–industry linkages	Denser collaboration and applied research channels	Weak linkages and limited demand articulation	ISB must translate needs and create problem-driven programmes
Financing ecosystem	Deeper capital markets and mission instruments	Shallow finance and high risk premiums	ISB must mobilise resources and de-risk experiments
Standards and quality systems	Mature standards infrastructure	Limited testing, certification, and enforcement	ISB must support standards and shared facilities

***Note**. Synthesis derived from comparative NIS scholarship and developing-country innovation capability literature. The stylised contrasts reflect differences in institutional coherence, learning infrastructures, and linkages that shape innovation performance and the need for system-building organisations (Lundvall, 1992; Bell & Pavitt, 1993; Arocena & Sutz, 2000).*

2.2.3 Absorptive capacity

Absorptive capacity is a critical concept for explaining why technology transfer frequently underperforms. Cohen and Levinthal (1990) define absorptive capacity as the ability to recognise the value of external knowledge, assimilate it, and apply it for commercial ends. This implies that “importing technology” is not a one-off procurement act. It is a learning process that depends on prior related knowledge, routines, and organisational investment.

Subsequent work distinguishes potential absorptive capacity from realised absorptive capacity. The point is that acquisition and assimilation do not necessarily lead to transformation and exploitation (Zahra and George, 2002). In developing-country settings,

absorptive capacity constraints often operate at multiple levels. A firm may lack engineering depth. A sector may lack testing infrastructure. A national system may lack stable institutions for skills formation and problem-driven research.

For Nepal, absorptive capacity matters in two linked ways. First, it sets the realistic scope of policy learning from Finland. Second, it implies that an ISB must invest in capability formation, not only in coordination routines. In biofuels, absorptive capacity also connects to sustainability governance. Credible sustainability standards require technical competence in measurement, verification, and enforcement.

2.2.4 Sectoral innovation systems and biofuels as a sector

NIS provides a macro frame, but sectoral approaches explain why innovation dynamics differ across industries. Malerba (2002) argues that sectoral systems vary by knowledge bases, technologies, demand conditions, actor structures, and institutions. Biofuels show this sector specificity clearly. The sector is shaped by feedstock supply conditions, land-use institutions, conversion technologies, distribution infrastructure, blending mandates, and sustainability standards. Policy design must therefore align multiple complementary components.

A sectoral lens helps clarify why general innovation policies may underperform in energy. Energy sectors are capital intensive and infrastructure bound. They are also politically sensitive because energy prices and security are strategic. New entrants face incumbent resistance and regulatory complexity. For these reasons, sectoral systems often require dedicated intermediaries and PROs to lower coordination costs and enable learning across actor groups (Malerba, 2002; Jacobsson and Johnson, 2000). **Figure 1** summarises the multi-level transition structure and highlights where biofuel innovation typically stalls across landscape, regime, and niche dynamics.

Biofuels further require integration across agriculture and energy regimes. This cross-regime nature can generate institutional misfits, such as unclear sustainability rules, conflicting land-use priorities, or fragmented responsibilities between energy and agriculture agencies. Such misfits make a strong case for an ISB that can operate across sectors and broker shared priorities.

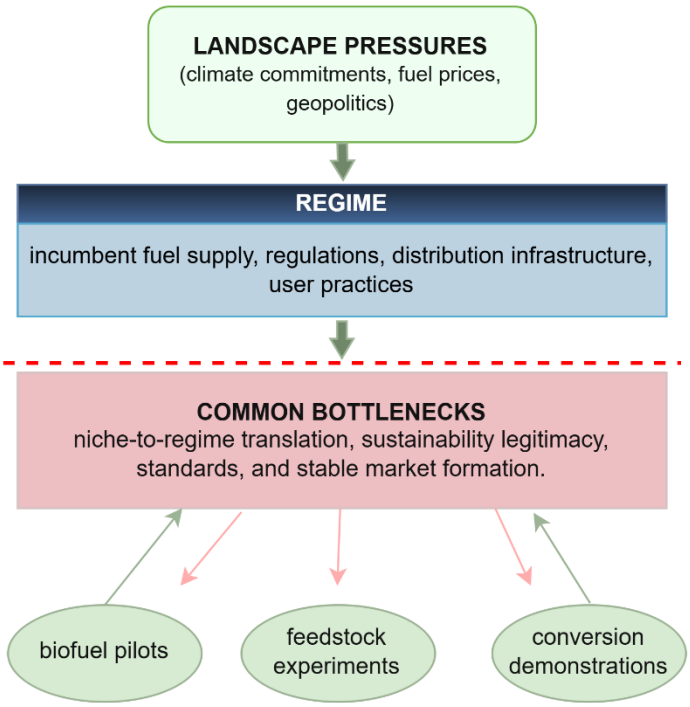

Figure 1. Multi-Level Perspective structure and where biofuel innovation typically struggles

Note. *Synthesis of the Multi-Level Perspective. The figure is adapted conceptually from sustainability transitions scholarship describing niche–regime–landscape dynamics and typical bottlenecks in niche-to-regime upscaling processes (Geels, 2002; Geels & Schot, 2007; Markard, Raven, & Truffer, 2012).*

2.3 Triple Helix (TH) and innovation-system builders (ISBs)

2.3.1 TH logic and the coordination problem

The TH model conceptualises innovation as an outcome of interactions among universities, industry, and government (Etzkowitz and Leydesdorff, 2000). The model is useful because it frames innovation as relational. Capabilities develop through collaboration, co-investment, and institutional support. However, TH interactions do not emerge automatically. They require convening power, trust, and organisational platforms that reduce transaction costs.

In developing-country settings, TH collaboration is often impeded by weak incentives for engagement, thin industrial demand for research, and limited public capacity to design

mission-oriented programmes. This creates a coordination problem: each actor may rationally underinvest because the benefits of collaboration are uncertain and partly collective.

2.3.2 ISBs and intermediaries

Innovation intermediaries are typically defined as actors that mediate between parties to facilitate innovation through brokering, networking, and enabling learning (Howells, 2006). In sustainability transitions, intermediaries are increasingly treated as critical because they speed alignment, reduce uncertainty, and help translate niche experiments into wider system change (Kivimaa et al., 2019). From a Triple Helix (TH) perspective, intermediaries and ISBs make university industry government collaboration workable by brokering relationships, translating agendas, and reducing coordination costs across the three spheres (Etzkowitz & Leydesdorff, 2000; Howells, 2006).

An ISB can be treated as a stronger and more purposive form of intermediary. The term signals more than connection. It signals construction. An ISB is expected to shape institutions, create shared infrastructure, mobilise resources, and build legitimacy for a new sector or pathway. This is particularly relevant for biofuels, where the innovation challenge is distributed across supply chains and governance arenas (Howells, 2006). The distinction matters. Many organisations can connect actors. Fewer can stabilise durable system functions. In this thesis, ISB effectiveness is defined as the ability to perform and stabilise the functions that enable coordinated innovation and scaling (Hekkert et al., 2007).

2.3.3 Public research organisations (PRO) as system coordinators

Within a Triple Helix (TH) configuration, public research organisations (PROs) often provide the practical mechanism through which university industry government interaction becomes routinised and productive. They contribute durable interface capacity through joint programmes, shared facilities, testing services, and demonstration platforms. This lowers coordination costs and helps convert scientific knowledge into sector-relevant solutions. In this sense, PROs can be understood as system coordinators that stabilise

collaboration in sectors where innovation depends on standards, infrastructure, and cumulative learning (Etzkowitz & Leydesdorff, 2000; Kivimaa et al., 2019).

In many national settings, Research and Technology Organisations (RTOs) form a prominent subtype of PRO. An RTO is typically a mission-oriented applied research organisation that operates between science and industry. It combines public funding with contract-based activities to deliver industry-facing research, piloting, testing, and technology translation. RTOs therefore support the TH logic by serving as a boundary-spanning node that enables knowledge circulation and joint problem solving across the three helices (Howells, 2006; Suvinen et al., 2010).

Finland is frequently described as a coordinated innovation system where public support institutions have played a sustained role in linking research to industrial upgrading. In this context, VTT Technical Research Centre of Finland is widely characterised as Finland's principal RTO, with an applied research and innovation mandate that includes demonstration support and industry-coupled programme work (Loikkanen, Hyytinen, & Konttinen, 2011; European Monitor of Industrial Ecosystems, n.d.). Organisational restructuring and governance reforms are relevant because they shape whether such institutions remain industry-relevant while maintaining public mission orientation (Loikkanen, Sarpong, & Mantere, 2011).

In Nepal, NAST is formally positioned as an apex science and technology body tasked with promoting science and technology for national development and supporting collaboration among researchers and experts (Nepal Academy of Science and Technology, n.d.). However, innovation-systems and intermediary scholarship suggests that mandate breadth alone is not sufficient for effective system-building. Performance depends on the extent to which the organisation can secure stable resources, focus on sector-specific priorities, embed industry-coupled problem-solving routines, and build legitimacy across relevant actor groups (Howells, 2006; Bergek et al., 2008; Malerba, 2002). These characteristics are not automatically present. They are design variables that can be assessed empirically in later chapters. Table 3 summarises the functions and capabilities expected from an innovation-system builder in a biofuel sector, providing a benchmark for subsequent comparison.

Table 3. Functional capabilities of an innovation-system builder (ISB) in a biofuel sector

Capability domain	What it entails in biofuels	Observable indicators
Knowledge creation and adaptation	Applied R&D, localising conversion processes, feedstock optimisation	Applied projects, patents, pilot results, technical reports
Standards and testing	Fuel quality testing, sustainability verification, certification support	Testing labs, standards participation, certification schemes
Network orchestration	Convening actors across agriculture, energy, and environment	Platforms, Memorandum of Understanding (MoUs), joint programmes, cluster initiatives
Demonstration and scale-up support	Pilots, demonstrations, learning-by-doing	Demo facilities, scaling grants, partnerships with utilities & firms
Legitimacy building	Public communication, sustainability governance, stakeholder engagement	Consultation processes, sustainability criteria adoption

Note. *Synthesis derived from intermediary and innovation-system function literature. The capability domains reflect established roles of innovation intermediaries and system-level functions required to move from knowledge creation to diffusion, demonstration, coordination, and legitimacy building (Howells, 2006; Hekkert et al., 2007; Bergek et al., 2008).*

2.4 Technology transfer, lesson-drawing, and institutional learning

2.4.1 Technology transfer beyond hardware

Technology transfer is frequently misconstrued as the movement of equipment or blueprints. In practice, transfer also involves tacit know-how, routines, maintenance capability, standards compliance, and the organisational practices that make technologies productive. The implication is that learning capacity is a binding constraint, because without absorptive capacity and organisational learning routines, imported knowledge remains underutilised or fails in operation (Zahra & George, 2002; Ockwell & Byrne, 2016).

In biofuels, transfer challenges emerge across multiple stages. Feedstock systems require agronomic knowledge and logistics. Conversion systems require operational capability

and quality control. Blending and distribution require standards and enforcement. End use depends on compatibility and user acceptance. Each stage depends on institutional support and coordinated system functions rather than isolated project implementation (Malerba, 2002; Bergek et al., 2008; Farrell et al., 2006).

2.4.2 Policy transfer and lesson-drawing

Policy transfer scholarship provides tools for assessing what can be learned from a foreign model. Dolowitz and Marsh (2000) define policy transfer as processes through which knowledge about policies, administrative arrangements, or institutions in one setting is used in the development of policies or institutions in another. They also highlight risks of uninformed transfer, incomplete transfer, and inappropriate transfer.

Lesson-drawing is closely related. Rose (1991) argues that lessons are not copied. They are adapted. The question is therefore not whether Finland's arrangements can be replicated in Nepal, but which elements can be translated under conditions of institutional distance.

Institutional distance refers to differences in regulatory systems, norms, and cognitive frames that shape how organisational practices travel (Kostova, 1999). Greater distance

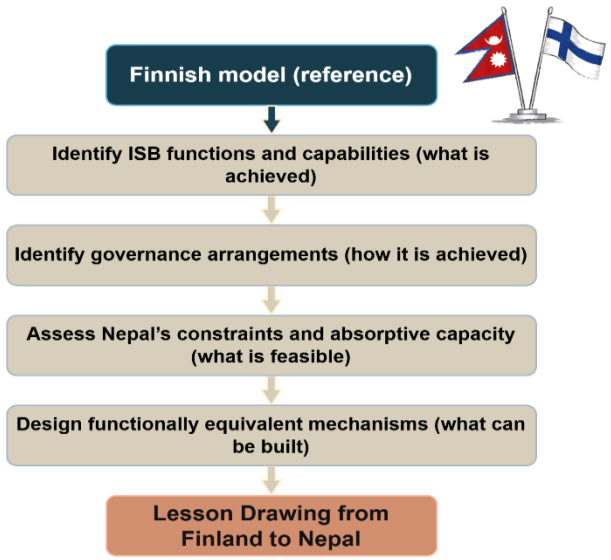

Figure 2. Functional lesson drawing sequence from Finland to Nepal.

Note. *The figure summarises how lessons are translated as functions and routines, not copied as organisational form. It operationalises transferability through institutional distance and absorptive capacity constraints (Rose, 1991; Kostova, 1999; Cohen & Levinthal, 1990).*

tends to reduce transfer fidelity and increases the need for local adaptation. This strengthens the role of absorptive capacity at organisational and system levels.

2.5 Climate Relevant Innovation-system Builder (CRIB)

2.5.1 The CRIB framework for understanding biofuel innovation needs

The CRIB framework was developed to address a recurrent limitation in international climate technology policy, namely an overemphasis on transferring technologies without building domestic innovation systems that enable learning, adaptation, and diffusion. Ockwell and Byrne (2016) argue that strengthening national systems of innovation is central for effective technology transfer, and propose CRIBs as organisations that actively build and coordinate innovation-system functions for climate-relevant technologies. This position is consistent with broader innovation-systems scholarship that treats innovation performance as a system property shaped by institutions, networks, and cumulative learning rather than by technology availability alone (Hekkert et al., 2007; Bergek et al., 2008).

CRIBs are conceptually aligned with an innovation-system builder lens but sharpen the focus for developing contexts. The framework emphasises building domestic capability, not only enabling adoption. It also highlights that climate-relevant technologies, including low-carbon fuels, often require system-level coordination because markets alone do not organise the necessary complementarities, particularly in infrastructure bound and regulation intensive sectors (Ockwell & Byrne, 2016; Malerba, 2002).

Biofuels require coordinated innovation across feedstock development, processing technologies, sustainability governance, and market formation. A CRIB lens therefore points to specific organisational functions that matter for sector development. The functional breakdown used here is an author synthesis derived from the CRIB argument on system building for climate technologies and from established innovation-system function approaches that specify the processes needed for knowledge development, diffusion, market formation, and legitimation (Ockwell & Byrne, 2016; Hekkert et al., 2007).

First, coordination and convening are required to align agriculture, energy, environment, and industry priorities and to reduce fragmentation across actor groups (Klerkx & Leeuwis, 2009; Kivimaa et al., 2019). Second, capability building is required to raise technical competence and standards compliance, because technology transfer depends on domestic learning and absorptive capacity (Zahra & George, 2002; Ockwell & Byrne, 2016). Third, knowledge diffusion is required to spread learning from pilots and reduce repeated failure cycles through system wide learning and feedback (Hekkert et al., 2007; Bergek et al., 2008). Fourth, legitimacy creation is required because biofuels are politically contested and sustainability criteria can shape access to markets and long-term policy durability (Fargione et al., 2008; Markard, Raven, & Truffer, 2012).

2.5.2 NAST as a potential CRIB

Positioning NAST as a potential CRIB is not a descriptive claim. It is an evaluative proposition. The question is whether NAST's mandate, governance, and resource base can be redesigned to perform CRIB functions for biofuels. This requires attention to three design variables: (1) Mandate coherence and sectoral focus. Broad mandates can dilute impact unless translated into prioritised programmes; (2) Stable funding and performance incentives. System-building requires continuity because capability development is cumulative; (3) Boundary-spanning legitimacy. A CRIB must be credible to firms, government agencies, and knowledge organisations (Ockwell & Byrne, 2016; Howells, 2006).

Table 4 translates the CRIB functions into concrete operational implications for building and sustaining biofuel innovation capacity.

Table 4. CRIB functions and operational implications for a biofuel sector

CRIB function	Operational meaning in biofuels	Examples of mechanisms
Build capabilities	Skills, labs, applied research routines	Training programmes, testing facilities, applied R&D portfolios
Coordinate actors	Reduce fragmentation and align investments	Inter-ministerial platforms, industry councils, cluster initiatives

Enable learning and diffusion	Turn pilots into shared knowledge	Demonstration networks, open technical guidelines, extension support
Create legitimacy	Sustainability governance and stakeholder trust	Sustainability criteria, transparent consultation, certification support
Mobilise resources	De-risk and finance early stages	Grants, blended finance, partnerships, procurement instruments

***Note**. Synthesis derived from the CRIB framework and related technology-transfer scholarship. The functions listed operationalise CRIB's emphasis on capability building, coordination, learning, legitimacy, and resource mobilisation for climate-relevant innovation pathways (Ockwell & Byrne, 2016; Dolowitz & Marsh, 2000; Cohen & Levinthal, 1990).*

2.6 Conceptual framework

2.6.1 Rationale for an integrative framework

This thesis requires a conceptual framework that can do three things at once. First, it must treat biofuel development as a socio-technical transition, where technologies, regulations, markets, and legitimacy co-evolve rather than move in a linear sequence (Geels, 2002; Markard, Raven, & Truffer, 2012). Second, it must explain how innovation is shaped by national coordination architectures rather than firm-level capabilities alone. The NIS perspective is therefore used to interpret how institutions, policy instruments, education and research infrastructures, and industry structures interact to enable or constrain innovation-led structural change (Freeman, 1995; Lundvall, 1992; Nelson, 1993). Third, it must specify what an ISB is expected to do in practice, especially in late-industrialising contexts where coordination failures and capability gaps are persistent. This thesis therefore draws on the TH perspective to conceptualise university-industry-government relations and the need for intermediating organisations (Etzkowitz & Leydesdorff, 2000), and it adopts the CRIB logic to operationalise system-building functions for climate-relevant sectors (Ockwell & Byrne, 2016).

Finally, because the study is explicitly comparative, the framework must include a disciplined theory of cross-national learning. Technology transfer and lesson-drawing are treated here not as institutional copying, but as a selective, conditional process shaped

by institutional distance and local absorptive capacity (Dolowitz & Marsh, 2000; Kostova, 1999; Rose, 1991).

2.6.2 Framework architecture

The integrated framework is organised into four analytical layers. These layers structure the comparison between Finland and Nepal and clarify the causal logic linking institutions to sector outcomes. Figure 3 summarises the four-layer framework and shows how cross-national learning is moderated by institutional distance and absorptive capacity.

Layer 1: Macro-institutional architecture (NIS layer).

This layer captures the enabling environment for innovation: policy stability, public funding logics, research governance, and the institutional incentives that shape collaboration and experimentation. In the Finnish case, the NIS layer is used to interpret why coordinated innovation policy and stable public research capacity can support long-term sectoral upgrading. In the Nepalese case, the same layer is used to diagnose fragmentation, mandate overlaps, and discontinuities that reduce the effectiveness of public support for biofuel innovation (Freeman, 1995; Lundvall, 1992).

Layer 2: Actor-relational configuration (TH layer).

This layer focuses on the structure and quality of interaction among universities, industry, and government. The TH approach is not used as a normative claim that collaboration automatically occurs; it is used to identify why collaboration often fails without brokerage, shared incentives, and boundary-spanning routines (Etzkowitz & Leydesdorff, 2000). In this thesis, the TH layer helps specify where an ISB must intervene: translating research into industrial use-cases, aligning policy design with technological trajectories, and reducing coordination costs.

Layer 3: Organisational mechanism (ISB and CRIB layer).

This layer is the analytical centre of the thesis. It treats VTT and NAST as focal organisations whose design, capabilities, and legitimacy determine whether system-building functions are performed consistently. CRIB strengthens this organisational lens by specifying what matters in climate-relevant sectors: not only knowledge generation, but also capability building, coordination, demonstration, and legitimacy formation (Ockwell & Byrne, 2016).

Layer 4: Cross-national learning and transferability conditions (technology transfer and lesson-drawing layer).

This layer governs how the Finland case can inform Nepal. Lesson-drawing is treated as a process that moves from scanning and selection to adaptation and prospective evaluation, with no presumption of replication (Rose, 1991). Policy transfer is treated as a spectrum from voluntary learning to forms of coercive diffusion, and it highlights failure risks when context is ignored (Dolowitz & Marsh, 2000). Institutional distance is used as a constraint on transfer, especially where local norms, enforcement capacity, and incentive systems differ from the source context (Kostova, 1999). Absorptive capacity is treated as the key mediating capability that determines whether imported routines and organisational templates can be assimilated and institutionalised (Cohen & Levinthal, 1990; Zahra & George, 2002). Figure 3 summarises the four-layer framework and shows how cross-national learning is moderated by institutional distance and absorptive capacity.

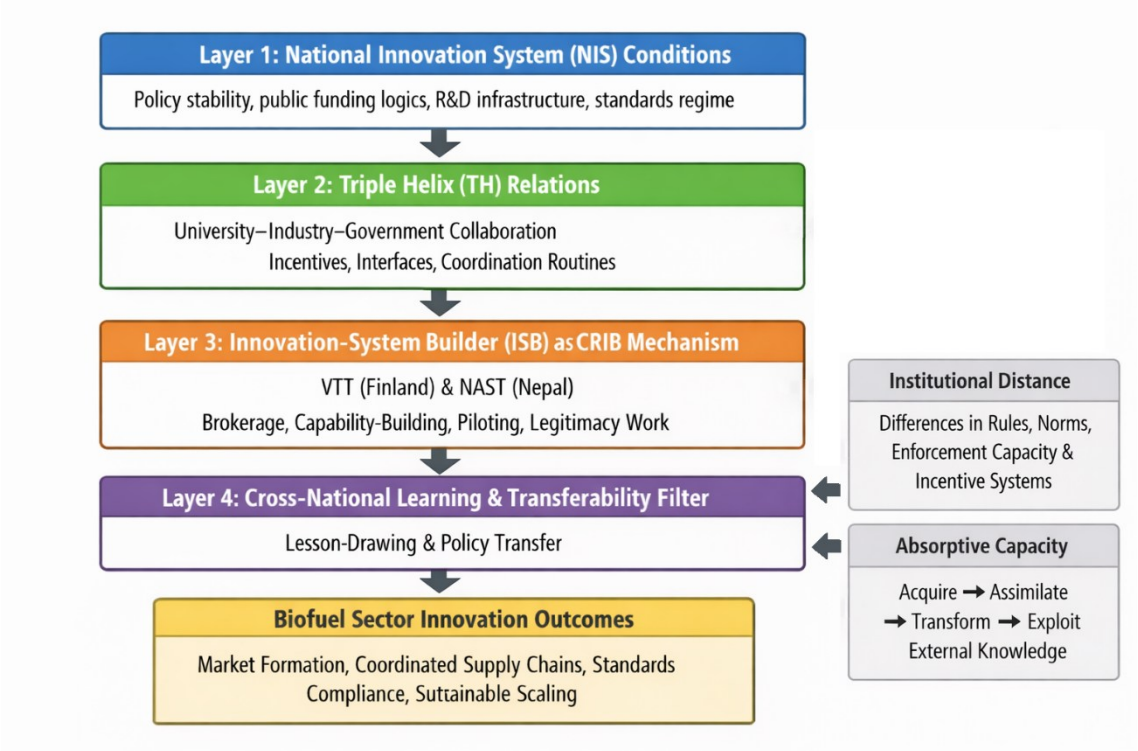

Figure 3. Framework summary diagram of the four-layer architecture and transferability moderators.

Note. *Author's synthesis derived from sustainability transitions and innovation-systems scholarship and the CRIB and policy transfer logic. The four-layer structure draws on innovation systems and Triple Helix*

perspectives, while the transferability moderators reflect lesson-drawing and institutional distance arguments and the role of absorptive capacity in knowledge assimilation (Lundvall, 1992; Etzkowitz & Leydesdorff, 2000; Dolowitz & Marsh, 2000; Kostova, 1999; Cohen & Levinthal, 1990; Ockwell & Byrne, 2016).

To translate the framework into a structured comparative lens, the thesis uses function-based categories to describe what an innovation-system builder is expected to accomplish. A functional lens is preferred because it supports comparison even when organisations differ in size, mandate, and governance structure. It also prevents the analysis from collapsing into “Finland has X, Nepal lacks X” descriptions. The function set used here combines CRIB emphasis with established innovation-system function approaches and intermediary scholarship. In practice, an ISB is expected to strengthen knowledge development and diffusion, enable experimentation and demonstration, orchestrate networks, mobilise resources and reduce risk, and build legitimacy through standards and sustainability governance (Bergek et al., 2008; Hekkert et al., 2007; Howells, 2006; Ockwell & Byrne, 2016).

This chapter defined the theoretical lenses that guide the study. It also clarified why cross national learning must be treated as selective adaptation under institutional distance and absorptive capacity constraints. The analytical propositions derived from this synthesis are evaluated in the cross case discussion in Chapter 6, where the Finland and Nepal evidence is used to refine the design logic for biofuel system building.

3 Methodology

3.1 Research philosophy and approach

This study examines how biofuel sectors can be strengthened through deliberate system-building in contexts with different institutional capacities. The research question is design oriented. It focuses on what an innovation-system builder (ISB) must do to make biofuel innovation cumulative, coordinated, and investable, and how lessons from a developed-country setting can be translated into a developing-country setting. A qualitative approach fits this purpose because system-building involves mandates, routines, coordination practices, and legitimacy work that are only partly visible through quantitative indicators. These elements are better traced through institutional analysis and interpreted evidence from documents and programme records (Yin, 2018; Bowen, 2009).

The study follows an abductive logic. Existing theory guides what is examined, but the analysis remains open to refining categories where the evidence suggests important context-specific mechanisms. This supports a disciplined balance between theory-driven structure and empirical sensitivity, which is appropriate when explaining complex institutional arrangements rather than testing a single variable relationship (Dubois & Gadde, 2002).

3.2 Research design

The research design is a comparative embedded case study. The two primary cases are Finland's bioenergy and biofuel innovation system and Nepal's emerging bioenergy and biofuel innovation system. Within these two national system cases, VTT and NAST are treated as embedded organisational cases. This design allows the study to compare not only national system conditions but also the organisational carriers through which system-building functions are performed, stabilised, or constrained in practice. The comparative purpose is functional learning. The study does not seek to replicate Finnish institutional form in Nepal. It extracts functions, governance principles, and capability requirements, then evaluates how these can be redesigned under Nepal's constraints (Rose, 1991; Dolowitz & Marsh, 2000).

The unit of analysis is the system-building role as carried by embedded organisations within their national innovation-system settings. VTT is analysed as the Finnish embedded case because it makes applied research, piloting, testing, and brokerage functions visible in a mature system. NAST is analysed as the Nepalese embedded case because it is the most plausible public organisational anchor for coordination, capability-building, and technology transfer in the national science and technology system. Complementary institutions are included where they shape standards, funding, market formation, and implementation conditions.

3.3 Case selection rationale

Finland and Nepal are selected because they represent contrasting national innovation-system conditions that make system-building mechanisms easier to observe. Finland provides a context where applied research infrastructure, continuity of funding, and coordinated innovation policy have supported long-term sector development. Nepal provides a context where energy security pressures are strong, but institutional and resource constraints limit sustained coordination across policy, research, and industry. This contrast improves analytical clarity. It helps distinguish context-specific institutional features from system-building functions that may be transferable.

The focal organisations are comparable in a functional sense. Both are national science and technology organisations with public mandates and boundary-spanning roles across research and policy. Differences in resources, governance stability, and embeddedness are not treated as background variation. They are treated as part of the explanation. These differences help identify which functions rely on mature institutional support and which functions could be developed through targeted organisational redesign. Institutional distance is therefore treated as a central constraint in assessing transferability, because differences in enforcement capacity, incentives, and legitimacy conditions shape what can be stabilised in the recipient context (Kostova, 1999).

3.4 Data collection strategy

The empirical material relies primarily on document analysis. This choice fits the research problem because it allows systematic reconstruction of institutional mandates,

funding logics, programme priorities, and public rationales over time. It also supports comparison across countries, since comparable document types exist in both contexts even when the depth and accessibility of evidence differ (Bowen, 2009). The document corpus includes national strategies and policy documents related to energy, climate, and innovation; organisational documents from the focal organisations such as annual reports, strategy documents, and programme portfolios; sector and agency reports that reflect implementation and evaluation; and peer-reviewed research that documents sector development, institutional constraints, and policy instrument performance.

Table 5 summarises the evidence plan and clarifies how each material type supports the analytical categories used later in the study.

Table 5. Data sources and analytical use

Source type	Examples of material	Main analytical use
National policy and strategy documents	Energy strategies, climate plans, bioeconomy and innovation policies	NIS conditions, mandate coherence, policy stability signals
Organisational documents	Strategies, annual reports, programme descriptions	ISB design, governance model, interface routines, capability profile
Sector and agency reports	Evaluations, roadmaps, implementation updates	Demonstration pathways, standards and testing infrastructure, de-risking instruments
Peer-reviewed studies	Sectoral feasibility studies and institutional analyses	Context triangulation and mechanism clarification

Note. Author synthesis derived from qualitative document analysis and case study evidence principles (Bowen, 2009; Yin, 2018)

3.5 Data analysis

Analysis proceeds in two stages. The first stage is within-case mapping. Each case is analysed independently using the same construct set, with attention to how system-building functions are performed and supported by governance arrangements, programme routines, and legitimacy mechanisms. This stage produces two structured case accounts,

one for Finland and one for Nepal, each organised around the same analytical categories to maintain comparability.

The second stage is cross-case translation. Lessons are extracted at the level of functions and governance principles rather than at the level of institutional form. Transferability is then assessed through two constraints. Institutional distance shapes enforceability, incentive alignment, and legitimacy conditions in the recipient context (Kostova, 1999). AC shapes whether imported routines and organisational templates can be learned, adapted, and institutionalised (Cohen & Levinthal, 1990; Zahra & George, 2002). This comparative logic follows lesson-drawing work that ends with prospective evaluation, meaning that the study asks what can plausibly work in Nepal rather than what appears impressive in Finland (Rose, 1991; Dolowitz & Marsh, 2000).

The coding scheme was derived deductively from the four-layer framework set out in Section 2.6. Layer 1 produced the code family NIS conditions. Layer 2 produced TH interaction quality. Layer 3 was operationalised through the ISB and CRIB mechanism, which was broken into organisational platform design, knowledge development and diffusion, experimentation and demonstration, network orchestration, resource mobilisation and de-risking, and legitimacy and sustainability governance. Layer 4 produced the transferability codes of institutional distance and absorptive capacity. Sector outcomes were coded separately as the observable effects that linked these layers to biofuel innovation performance. Table 6 is therefore the operational form of Figure 3, rather than a separate conceptual framework.

Table 6. Deductive operationalisation of the four-layer conceptual framework

Construct	Definition	Example empirical indicators	Typical data sources
NIS conditions	National-level institutional architecture shaping innovation incentives	policy stability, public R&D funding continuity, governance coherence	strategies, budgets, legislation, agency reports

TH interaction quality	Strength and structure of university–industry–government relations	co-funded programmes, joint projects, interface routines, industry pull	programme documents, MOUs
ISB design and capability	Organisational capacity to coordinate and build system functions	mandate clarity, funding model, staff skills, boundary routines	annual reports, organisational charts
Knowledge development and diffusion	Generating and translating sector-relevant knowledge	applied research outputs, training, uptake by firms	publications, patents, training records
Experimentation and demonstration	Enabling piloting and learning-by-doing	demonstration projects, testing facilities, evaluation routines	project portfolios, evaluation reports
Network orchestration	Building and stabilising actor networks	convening platforms, partnership density, brokerage roles	stakeholder maps, event records
Resource mobilisation and de-risking	Mobilising finance and reducing innovation risk	funding instruments, risk-sharing mechanisms, investment crowd-in	budgets, grant calls, project finance records
Legitimacy and sustainability governance	Building acceptance and standards for scaling	sustainability criteria, certification links, stakeholder legitimacy	standards documents, stakeholder statements
Transferability conditions	Constraints on applying lessons from Finland to Nepal	institutional distance, AC, enforcement feasibility	comparative institutional analysis
Sector outcomes	Observable sector performance results	market formation signals, technology readiness, scaling pathways	market and policy data, project outcomes

Note. Author synthesis derived from innovation-system function approaches, intermediary theory, and CRIB's functional emphasis (Bergek et al., 2008; Hekkert et al., 2007; Howells, 2006; Ockwell & Byrne, 2016).

No additional conceptual figure is used at this stage, because Figure 3 already presents the theoretical architecture and Table 6 translates that architecture into codes, indicators, and evidence sources.

3.6 Research quality and ethics

Research quality is addressed through credibility, dependability, confirmability, and transferability. Credibility is supported through triangulation across policy documents, organisational material, programme records, and peer-reviewed studies. Dependability is supported by applying the same coding framework across both cases and by maintaining a clear record of coding decisions and synthesis memos. Confirmability is strengthened by separating evidence excerpts from interpretation and by linking claims to traceable sources. Transferability is addressed by reporting results as function-level design principles, with explicit attention to institutional distance and absorptive capacity constraints that limit direct replication (Lincoln & Guba, 1985; Yin, 2018). Ethical care in the study is tied to accurate representation of documentary sources, transparent interpretation, and consistent citation practice throughout the thesis.

4 Case study Finland: a mature innovation system for bioenergy and a reference context for biofuel system-building

This chapter analyses Finland as the reference case for system-building in bioenergy and biofuels. The purpose is to document the institutional conditions that support cumulative learning and coordinated scaling, and to specify how a focal organisation performs the ISB role. The analysis follows the four-layer framework developed in Chapter 2. It begins with Finland's transition context and the position of bioenergy. It then outlines the innovation system architecture for bioenergy and transport fuels. It then examines VTT as the focal organisational mechanism. The chapter closes by mapping VTT to the CRIB and ISB functions that later support conditional lesson-drawing (International Energy Agency [IEA], 2023).

4.1 Context of the energy transition and the position of bioenergy in Finland

Finland's energy transformation is influenced by a strong climate policy and a long-standing dependence on energy production based on biomass. The country has a legal commitment to carbon neutrality by 2035, and national policy has backed the growth of renewable electricity and low carbon heat and managed energy security issues. The International Energy Agency's (IEA) review says that Finland has one of the lowest shares of fossil fuels in energy supply among IEA members. It also underlines nagging problems in transport and in the land use sector where carbon sinks have weakened. This context is important for biofuels because it situates bioenergy within a broader debate around sustainability and forest resources as well as long-run legitimacy (IEA, 2023).

Bioenergy is the stronghold of Finnish renewable profile. In 2021, the share of renewables in total final energy consumption was about 48 percent with bioenergy related the largest share of renewable supply. According to the same review, renewables accounted for approximately 43 percent of gross final energy consumption in 2021 and that bioenergy accounted for most of renewable energy during this time. This is a pattern that reflects the industrial structure of Finland and particularly the forest industry as well as the

availability of wood-based residues and by-products for heat, power and biorefining pathways (IEA, 2023).

Finland's transition has also been a diversifying one that has simultaneously been bioenergy heavy. European Environment Agency reporting suggests that approximately 70 percent of Finnish renewable energy has been bioenergy, produced mainly from wood waste streams, and notes rapid growth in wind power too. Eurostat data makes Finland one of the front-runners in the European Union with regards to the share of renewable energy in gross final energy consumption in 2023. For this thesis, the combination is important as it demonstrates the impact possibilities of a biomass-based system being able to coexist with the expansion in other renewables at high pace if the policy and investment setting are stable (European Environment Agency [EEA], 2025) (Eurostat, 2024).

Transport is where the question of biofuels is most visible. The IEA review shows that renewable share in transport is behind heating and electricity and finds transport to be an area where fossil fuel dependence remains. Finland has solved this partially with a distribution obligation that establishes a quota for the sale of renewable fuels for transport fuels. According to an IEA policy entry, an Act on the Promotion of Biofuels in Transport has been revised and the distribution obligation is at least 13.5 percent in 2024. European Commission related policy summaries also specify sub-targets and source limits which influence which biofuels count towards compliance. These rules are relevant in this study because they serve as a market formation and legitimacy mechanism. They generate predictable demand and limit feedstocks and sustainability profiles (IEA, 2023) (IEA, 2024) (European Parliament & Council, 2018).

Bioenergy's strategic role is also a connection to the national bioeconomy goals. Finland's bioeconomy strategy goes until 2035 and envisions the bioeconomy as a provider of higher value added and a contributor to climate goals. The strategy is multi-ministerial, which sends the message of being cross-cutting rather than niche framing. For biofuels this is important as credible scaling requires alignment in areas of energy, industry, agriculture, environment, education and transport. Finland's strategy makes that intent for coordination explicit (Finnish Government, 2022).

These national commitments also sit within a wider European policy and financing context. Finland's renewable energy and transport fuel rules are shaped by EU climate and energy governance, especially the wider Green Deal direction and the renewable energy framework that sets sustainability criteria, transport targets, and compliance rules across member states. This matters for the present study because Finland's biofuel system is not supported by national institutions alone. It is reinforced by a regional policy environment that strengthens investment credibility, supports demonstration, and links domestic implementation to wider European decarbonisation goals (European Commission, 2019; European Parliament & Council, 2018; Huttunen et al., 2024).

These conditions provide a useful context of reference for system building. Finland's bioenergy position is not solely explained by the availability of biomass. It is also shaped by institutional coherence, stable investment expectations, as well as organisations that translate policy goals into applied research, pilots, standards and industry-facing problem solving. This is more apparent when the analysis moves from sector context to innovation system architecture (IEA, 2023).

4.2 Design of the Finnish innovation system for bioenergy

Finland's innovation system for bioenergy and biofuels can be characterized as a coordinated system with connections between policy steering, public funding, applied research infrastructure, and industrial implementation. From a National Innovation System (NIS) point of view, this architecture exhibits comparatively high mandate clarity, stable public support mechanisms, and strong organisational capacity for applied research and demonstration. The update to the national energy and climate plan gives a recent example of this logic of coordination. It frames targets and measures in the areas of decarbonisation, energy security, market design and research and innovation. It also has an explicit renewable energy ambition towards 2030, which helps to support credibility and investment expectations (Huttunen et al., 2024).

Governance is supported by strategy alignment. Finland's bioeconomy strategy is the result of a multi-ministerial process and situates the bioeconomy in the context of economic policy and industrial renewal. This removes the threat of biofuels being a temporary theme. It also allows a frame of coordination supporting the long-term building of

capability. For ISB analysis, this is important because system building functions have a cumulative nature. They need continuity in programmes, skills and infrastructure (Finnish Government, 2022).

Public funding and de-risking instruments are another enabling layer. Business Finland's energy aid instrument aims to support investments and audits that improve energy efficiency and encourage renewable energy by means of new technology projects, taking express account of the reduction of technical and financial risks. This sort of support is important for biofuel development because the early pilots and demonstrations are met with high levels of uncertainty and can be difficult to fund privately. Co-funding mitigates downside exposure and facilitates the learning-by-doing (Business Finland, 2025).

The research funding arena is also favourable to knowledge development in the bioeconomy. The Research Council of Finland has supported dedicated programmes, such as BioFuture2025, which seeks to build up the knowledge base and make it possible to achieve progress in bio-based solutions. Even when programmes are not biofuels-only, they con-tribute to the wider scientific and engineering base for biomass conversion, process optimisation, sustainability assessment and supply chain innovation. For this thesis, the issue is that ISB capability requires a credible domestic knowledge base and a stable pipeline of expertise (Research Council of Finland, n.d.).

The Triple Helix (TH) layer is visible in Finland through dense collaboration routines that connect universities, industry, and government agencies via applied programmes and shared infrastructure. This is where intermediating organisations matter. Boundary-spanning roles are institutionalised within research and technology organisations and other intermediaries. They reduce coordination costs and translate problems across communities. They also provide shared facilities and testing capacity that individual firms would be unlikely to build alone. In this study, VTT is treated as the focal organisation because it sits at this interface and provides a stable platform for applied research, pilots, and technology translation (VTT, n.d.-a) (VTT, n.d.-b).

A practical indicator of this architecture is the presence of open-access pilot and testing environments that function as shared learning platforms. The City of Espoo describes the VTT Bioruukki pilot centre as a major research and innovation platform for process

technologies of bio-based products and circular economy solutions, established in 2015, and positioned as a Nordic-scale platform for pilot work. Such facilities are not only technical assets. They are also coordination devices. They bring firms, researchers, and policy actors into repeated interaction around pilots, standards, and feasibility assessments. This is consistent with the idea that transition progress depends on stable niches where experimentation is linked to scaling pathways (City of Espoo, 2024).

Figure 4 summarises the Finnish bioenergy innovation system architecture and to show where policy steering, funding instruments, applied research, and industry implementation interact.

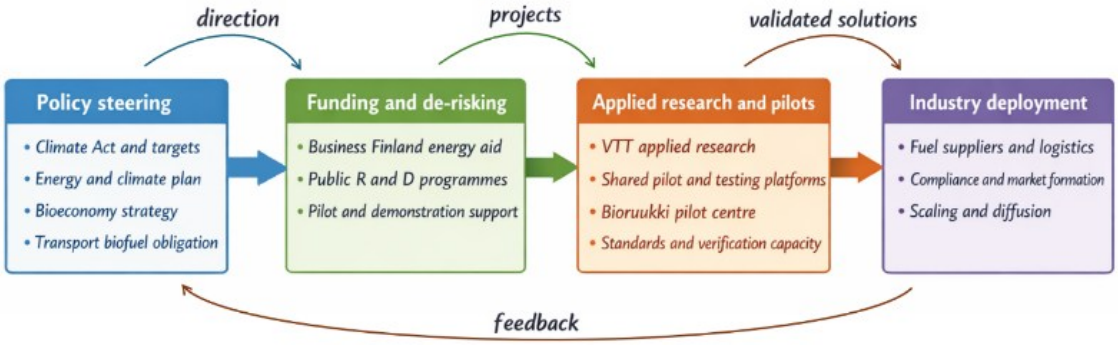

Figure 4. Finland's bioenergy innovation system architecture and the role of shared pilot infrastructure.

***Note**. Author synthesis derived from Finnish energy policy planning documents and the description of applied research and pilot platforms used for technology development and demonstration (Huttunen et al., 2024) (IEA, 2023) (City of Espoo, 2024).*

4.3 VTT as an innovation-system builder

VTT is analysed here as the focal ISB within Finland's bioenergy and biofuel related innovation environment. The analysis focuses on mandate and governance, funding and incentives, boundary-spanning roles, and concrete capabilities that enable system-building functions. This follows the logic that ISB performance is not a label. It is an observable set of functions and routines that stabilise coordination and learning.

VTT's mandate and governance position it as a public mission organisation with industry-facing delivery. VTT is a fully state-owned limited liability company operating under the ownership steering of the Ministry of Economic Affairs and Employment. Its governance description emphasises an independent and impartial role and a special duty to promote

utilisation and commercialisation of research and technology in commerce and society. This is relevant for ISB analysis because neutrality and credibility are part of boundary-spanning legitimacy. They allow VTT to convene competing actors, work across sectors, and support policy and industry simultaneously without being seen as captured by a single interest group (VTT, n.d.-a).

VTT's funding model also aligns with a system-building role because it combines public mission finance with competitive project funding and commercial work. VTT reports that its operating income is composed of government grants, jointly funded competitive public funding, and commercial activities. This structure matters because it creates incentives to remain industry-relevant while maintaining public mission capacity for long-term competence development and early-stage technology work that may not yield immediate commercial returns. For biofuels, where conversion technologies, standards, and sustainability governance co-evolve, such a funding mix supports continuity across research, piloting, and demonstration (VTT, n.d.-b).

The role of VTT as a boundary-spanning organisation is visible in how it integrates research infrastructure with piloting and demonstration capability. The VTT annual and sustainability report highlights VTT's applied research mission and describes investments in research and testing environments, including the expansion of the VTT Bioruukki research and testing environment in Espoo for developing clean energy solutions. This statement is important for the thesis because it links institutional capability to material infrastructure. Piloting environments reduce the gap between laboratory results and industrial scaling by enabling process optimisation, reliability testing, and learning under semi-realistic conditions (VTT, 2025).

Bioruukki is also described externally as an innovation platform that supports companies and organisations in developing bio-based and circular economy solutions. The City of Espoo notes that Bioruukki was established in 2015 and functions as a pilot centre and innovation platform that supports development work by organisations of different sizes. This open-access logic matters for system-building because it broadens participation beyond large incumbents. It also creates shared learning loops where results from pilots can diffuse across networks and shape standards and expectations (City of Espoo, 2024).

VTT's ISB role is further reinforced by its position in the national quality and measurement infrastructure. VTT reports that Finland's national metrology institute and national standards laboratory is part of VTT. This institutional feature is directly relevant to biofuels and renewable fuels because scaling depends on credible measurement, testing, and verification. Standards capacity affects fuel quality compliance, sustainability verification, and confidence across supply chains. When these functions are embedded in a trusted organisation, legitimacy and market formation become easier to stabilise (VTT, n.d.-a).

A final ISB dimension is ecosystem and network work. VTT describes its societal role in active cooperation between stakeholders, including companies, universities, research funding agencies, and ministries, with the aim of fostering information flows and a common vision of priority areas. In ISB terms, this describes network orchestration and brokerage as routine activities, not as ad hoc project tasks. It also aligns with the TH view that collaboration requires interface capacity and repeated interaction supported by an intermediary that can translate agendas and reduce coordination costs (VTT, n.d.-c).

Table 7 summarises VTT's organisational features that are directly relevant to ISB performance in the bioenergy and biofuel domain.

Table 7. Organisational features of VTT relevant to ISB performance in bioenergy and biofuels

Organisational feature	What it means for the ISB role	Evidence to cite in the Finland case
Ownership and governance position	Public mission with credibility to convene across actor groups	VTT described as fully state-owned and operating under ownership steering; independent and impartial role and special duty
Mandate and mission orientation	Applied research and technology translation aligned to societal and industry impact	VTT mission framed around applied research and science-based innovation with societal and commercial impact
Funding model mix	Continuity for long-term competence building plus	Operating income described as combining government grants, jointly

	incentives for industry relevance	funded competitive public funding, and commercial activities
Boundary-spanning role	System coordination through routine cooperation and agenda alignment	VTT describes active cooperation with companies, universities, funding agencies, and ministries to foster information flows and shared priorities
Shared pilot and testing infrastructure	Learning-by-doing and scale-up support through semi-industrial environments	Bioruukki described as a pilot centre and innovation platform; VTT reports expansion of research and testing environments
Demonstration and piloting support	Bridging lab to industry through piloting, process optimisation, feasibility testing	Bioruukki positioned as a Nordic-scale platform for piloting and process technology development
Standards, metrology, and verification capacity	Credible measurement and compliance support for fuels and sustainability claims	VTT reports that Finland's national metrology institute and national standards laboratory is part of VTT
Legitimacy and neutrality	Trust and acceptance for cross-sector coordination and standards-related work	Governance text emphasises independent and impartial role, supporting neutrality in multi-stakeholder settings

***Note**. Author synthesis derived from VTT's governance and strategy descriptions and from reporting on research infrastructure and piloting environments (VTT, n.d.-a) (VTT, n.d.-b) (VTT, 2025) (City of Espoo, 2024).*

4.4 Mapping VTT to CRIB and ISB functions

This section maps VTT's role to the CRIB and ISB functions defined in Chapter 2 and operationalised in Chapter 3. The purpose is not to claim that Finland's institutional model

can be copied. The purpose is to identify function performance and the enabling conditions that make those functions durable. This function-first mapping is also the basis for later conditional lesson-drawing.

In the CRIB framing, a system-building organisation supports domestic capability building, actor coordination, learning and diffusion, legitimacy formation, and mobilisation of resources. VTT exhibits these functions through applied research capacity, shared pilot infrastructure, network routines, and institutional credibility. Its governance and funding model support continuity, while its infrastructure supports learning-by-doing and translation from research to industrial use. VTT's public mission and impartiality strengthen legitimacy. Its role in standards and metrology supports measurable compliance and verification. Taken together, these features illustrate a practical template for system-building in climate-relevant sectors (Ockwell & Byrne, 2016) (VTT, n.d.-a) (VTT, n.d.-b).

Table 8 maps the CRIB functions to observable evidence for VTT within the Finnish context. The evidence is drawn from VTT's official reporting and governance documentation and from the description of Bioruukki as a shared pilot platform.

Table 8. CRIB and ISB function map for VTT in the Finnish bioenergy and biofuel context

Function category	What it means	Evidence signals in the Finland case
Build capabilities	Applied research, skills, and infrastructure for technology development	Stable applied research mandate; public mission and strategic competence development; investment in research and testing environments
Coordinate actors	Convening and brokerage across policy, research, and industry	Stakeholder cooperation role described as part of VTT's societal mission; ownership steering supports cross-sector alignment
Enable learning and diffusion	Pilots, demonstration, and knowledge circulation across networks	Shared pilot and testing environments such as Bioruukki; pilots that support learning-by-doing and diffusion through access to facilities

Create legitimacy	Credibility, standards support, and verification capacity	Independent and impartial role; embedded metrology and standards laboratory functions; ability to support quality assurance and verification
Mobilise resources and de-risk	Co-funded projects and instruments that reduce early-stage risk	Funding model combining grants, competitive funding, and commercial work; linkages to public programmes that support novel technology and pilots

Note. *Author synthesis derived from VTT governance documents, VTT reporting, and municipal descriptions of the Bioruukki pilot platform (VTT, n.d.-a) (VTT, 2025) (City of Espoo, 2024).*

Figure 5 visualises how VTT's functions connect to a biofuel innovation chain, from feedstock and conversion development to testing, demonstration, and market-facing standardisation. The figure is used as a descriptive device for the Finland case and as a bridge to the later transferability discussion, where functions are abstracted and then assessed against Nepal's constraints.

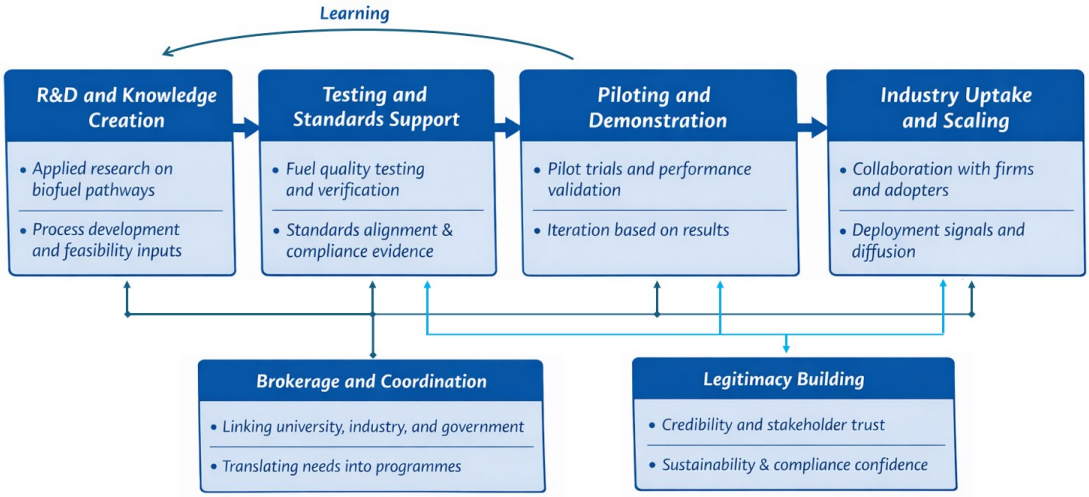

Figure 5. VTT functional map across the biofuel innovation chain
Note. *Author synthesis derived from the CRIB function lens and VTT's described roles in applied research, piloting, and standards-related infrastructure (Ockwell & Byrne, 2016) (VTT, 2025).*

4.5 Summary of Findings from Case 1

This analysis positioned Finland as a mature reference context where bioenergy has been scaled through long term policy commitment, coordinated innovation governance, and

strong applied research infrastructure (IEA, 2023; Finnish Government, 2022). The case showed that biofuels in transport are supported by predictable market formation instruments, including the distribution obligation, which stabilises demand while linking compliance to sustainability rules (IEA, 2024). The core analytical contribution of the chapter was to specify how VTT functions as an innovation system builder through a bundled capability set that includes applied research, shared piloting and demonstration capacity, standards and metrology related functions, and routine brokerage across universities, industry, and government (VTT, n.d.-a; VTT, 2025; City of Espoo, 2024). Mapping VTT to the CRIB lens clarified that Finland's strength is institutional as well as technological, because system functions are carried by durable organisations and instruments rather than by isolated projects (Howells, 2006; Bergek et al., 2008; Ockwell & Byrne, 2016). This analysis therefore established the functional benchmark used later for conditional lesson drawing to Nepal.

5 Case study Nepal: an emerging innovation system for bioenergy and a developing context for biofuel system building

This section presents the Nepal case. It follows the same construct set used in the Finland chapter. The focus is on biofuels and the institutions that shape cumulative learning in that sector. The chapter links three layers. The first layer is national conditions that influence innovation incentives and continuity. The second layer is the structure of university industry government interaction. The third layer is the presence or absence of an ISB that can stabilise system functions over time (Edquist, 1997; Etzkowitz & Leydesdorff, 2000; Bergek et al., 2008).

The Nepal case is treated as a capability-building context in which the institutional conditions for biofuel development remain uneven. The chapter examines how national conditions, coordination structures, and organisational roles shape the emergence of biofuel-related system functions. Particular attention is given to NAST as a potential public actor for capability-building, coordination, and institutional support in the biofuel domain.

5.1 Nepal’s energy transition context and fuel security position

Nepal has got energy system structurally exposed to liquid fuel import. Petroleum products enter through cross-border logistics and pricing channels which are not completely under Nepal's control. This exposure influences the stability of the macroeconomy and the regular mobility. It also determines political confidence in energy supply.

Government reporting verifies that Nepal is still highly dependent on imported petrol, diesel, LPG, and aviation turbine fuel which are all imported through the India corridor and are stored in a limited number of depots (Water and Energy Commission Secretariat, 2024). This is important as fuel security is determined by logistics and concentration of storage and international prices in Nepal.

Nepal Oil Corporation information lends credence to the same dependence. In Nepal's fiscal year (FY) 2078/79 (which corresponds roughly to mid-July 2021 to mid-July 2022), the corporation imported approximately 736,276 kL of petrol, 1,723,557 kL of diesel, and

536,028 MT of LPG, and the sales volumes were near import volumes (Nepal Oil Corporation, n.d.). These figures are here given as background conditions and not as preliminary analytical results. Their implications for system-building are taken up later in the summary of this chapter and in Chapter 6.

At the same time, Nepal's electricity system is growing, and the electrification of transport is starting to change the long run substitution landscape. A high level of electrification and increased policy focus on electric mobility can be observed in the Energy Sector Synopsis Report (Water and Energy Commission Secretariat, 2024). This does not take the relevance of biofuels away. It reduces their likely role in some light-duty segments but leaves continuing relevance in hard-to-electrify applications, supply security hedging and domestic value creation in selected bio-based fuel chains.

Climate commitments are one additional layer. Nepal's NDC 3.0 outlines a pathway with a renewable energy expansion, low emission technologies and international assistance for technological transfer and capacity building (Government of Nepal, 2025). This framing bolsters the legitimacy case for the low carbon fuels. Yet Nepal does not have the benefit of a regional policy and investment ecosystem anywhere close to that of the European Union, providing Finland another level of regulatory alignment, funding and implementation strength. Nepal therefore is more on its own, with more reliance on coordination within its domestic institutions, the credibility of national policies and local source support of investments. For that reason, climate ambition does not fill the gap between the policy intent and sector delivery.

5.2 Nepal’s innovation system architecture for biofuel and bioenergy

Nepal's bioenergy and biofuel scenario is a case of partial capability rather than an integrated sectoral system. The country has some previous experience with modern bioenergy, most notably in the household and community sectors, but this is not currently reflected in the equally developed liquid biofuels sector. The most obvious example is biogas dissemination, where it is evident that well-coordinated programme design, rules on subsidies, and service networks can support long-term adoption in a resource-constrained context (AEPC, 2021). This is important because it indicates that Nepal is not

starting from scratch in bioenergy. At the same time that experience does not mean that the institutional and market conditions for liquid biofuels are in place.

For liquid biofuels, the most obvious routes are, in the Nepalese context, ethanol and biodiesel. Ethanol has been discussed primarily in relation to molasses from the sugar industry which gives the clearest near term feedstock base for blending with petrol. Earlier research has studied molasses-based ethanol development in Nepal using life cycle energy analysis and revealed that the viability of molasses-based ethanol depends not only on the conversion technology, but also on the system boundaries, treatment of co-products and governance of wider chains (Khatiwada & Silveira, 2009). Biodiesel has been talked about primarily in the context of non edible oil crops such as jatropha. Yet research on this pathway highlights significant feasibility constraints that are related to yields, land-use trade-offs, transaction costs, and weak institutional support, which limit the commercial readiness of this pathway under present conditions (Timilsina & Tiwari, 2015). In other words, Nepal does have identifiable feedstock options but these are conditional rather than fully established.

This distinction does clarify what Nepal has and what it does not have. Nepal has relevant biomass options, prior bioenergy experience and a legitimate policy interest in renewable fuels. What it lacks at present is a stable system of liquid biofuel backed up by stable feedstock aggregation, continuity of production at commercial scale, blending routines, testing of fuel quality, assurance of vehicle compatibility and clear procurement and enforcement mechanism. The challenge therefore is not a simple one of conversion technology. It is one of the building of a governed chain from feedstock to final fuel use.

The demand side signal is more visible. Nepal's Cabinet has approved an order related to ethanol blended petrol, which paves the way for a clearer legal space for blended fuel, and related procurement rules that are to follow (Radio Nepal, 2026a). Public reporting also suggests that preparations are underway for implementation of a ten percent ethanol blending policy, with discussions between Nepal Oil Corporation and government agencies in pricing, quality standards and supplier selection (Radio Nepal, 2026b). This is important because it implies movement beyond broad policy intent and towards a more concrete market signal.

Even so, the appearance of a blending signal is not in itself the solution to the fundamental system gaps. Fuel quality becomes a governance rather than technical issue. Without the capacity to test and a clear chain of custody, blending can result in disputes over performance, compliance and liability. Feedstock supply and production capacity are also still a binding constraint. Public reporting indicates that the large scale commercial ethanol production is not fully in place and procurement and pricing rules still need to be further clarified (Radio Nepal, 2026b). Legitimacy is also tenuous. Bio-fuels can be framed as climate relevant and domestically useful, but on the other hand, in bio-fuel). -Bio-fuel can be a source of concern with respect to land use, food competition and procurement rents. For that reason, credibility relies much less on policy rhetoric and more on standards, verification and transparent governance.

From the perspective of innovation systems, these sector conditions are embedded in an emerging but fragmented architecture. Nepal has the relevant actor categories such as ministries, public agencies, universities, standards bodies, the national oil company and private firms. Yet their interaction is not routinised as is the case in mature systems. Responsibilities that are pertinent to biofuels are dispersed among energy, industry, agriculture, trade, standards, and research institutions. This makes coordination difficult and undermines continuity in programme design and implementation (Edquist, 1997; Berкara et al., 2008).

The research and coordination environment also determines what is feasible. In developing country environments, low demand for applied knowledge and poor interface structures may limit cumulative innovation even in the presence of research bodies (Arocena & Sutz, 2010). This is important in Nepal due to the crucial role of biofuel development requires not only technical studies. It involves the need for stable links between research, standards, piloting, procurement, and the market actors. Universities, public agencies, and firms are present, but inter-action is just one thing that produces a stable evolution of innovations. Biofuels demand the repeated coordination tasks that are in between actors. These include translation of policy goals into programmes, specification

of standards, organisation of pilot consortia and building of trust with users. Intermediary scholarship considers these as core functions and not side activities (Howells, 2006; Suvinen et al., 2010).

In this sense Nepal innovation system architecture for bioenergy and biofuels is emerging and not consolidated. It has resource potential, policy interest and some prior experience of implementation but still does not possess the stable institutional routines that link knowledge generation to sector formation. This makes the role of a system-building organisation especially important. The next section thus considers whether or not NAST is able to credibly perform that role.

5.3 NAST as an innovation-system builder candidate

NAST is analysed here as the focal organisational candidate within Nepal's emerging biofuel innovation environment. The purpose is not to assume that NAST already performs an ISB role in the full sense. The purpose is to assess whether its mandate, legal basis, and institutional position give it a plausible foundation for such a role under Nepal's conditions. This mirrors the logic used in the Finland case, where VTT was examined not simply as an organisation, but as a carrier of specific system-building functions.

NAST is established under the Nepal Academy of Science and Technology Act, 2048 (1991). The Act defines NAST as an autonomous body and assigns objectives that include national science and technology development, protection and modernisation of indigenous technology, research, and identification of appropriate technology with support for technology transfer (Government of Nepal, 1991). At a formal level, this gives NAST broad legitimacy within Nepal's science and technology system.

The Act also assigns functions that map closely to coordination and interface work. These include conducting priority-based study and research, assisting government in policy formulation and implementation related to technology transfer, running programmes in a coordinated manner with domestic and foreign science and technology organisations, and maintaining documentation and information systems (Government of Nepal, 1991). These provisions matter because they provide a legal basis for a system-building role that extends beyond laboratory research alone.

Yet an ISB role depends on more than formal mandate. It requires routines, infrastructure, sectoral focus, and institutional credibility in practice. In Finland, the ISB role could be observed through stable applied research funding, shared pilot infrastructure, embedded standards capacity, and repeated industry-facing interaction. For Nepal, the issue is whether NAST can perform a narrower but credible set of similar functions adapted to local constraints.

Two observations frame the assessment. First, NAST's cross-sector status can be an advantage because it gives the organisation convening potential across multiple ministries and stakeholder groups. At the same time, broad mandate coverage can dilute impact unless it is translated into prioritised programme lines. Second, biofuels require specialised testing, verification, and coordination pathways. A general science mandate does not automatically produce these capabilities. They require deliberate investment and practical linkages with standards bodies, fuel market operators, producers, and relevant ministries.

For that reason, NAST is best understood here as an innovation-system builder candidate rather than as an already consolidated system builder. Its legal position gives it a plausible institutional anchor. The remaining question is functional. Which biofuel-relevant functions can NAST already support, which remain weak, and which could be built in a realistic phased manner? That question is addressed in the next section through the CRIB and ISB function lens.

5.4 Mapping NAST to CRIB and ISB functions

This section uses the same function-first logic applied in the Finland case. The objective is not to evaluate NAST in abstract terms, but to assess its role through a set of specific system functions. These functions include knowledge development, coordination, experimentation, legitimacy support, and resource mobilisation. The practical question is what functions are currently visible, what remains weak, and where NAST could credibly expand under Nepal's institutional conditions.

5.4.1 Knowledge development/capability building

Knowledge development in biofuels involves feedstock evaluation, conversion process development, blending studies and sustainability measurement. In Nepal, there is relevant re-search in the academic record. Examples are life cycle analysis of molasses ethanol and feasibility work on pathways for biodiesel (Khatiwada and Silveira 2009; Timilsina and Tiwari 2015). This suggests a minimum level of technical competence.

The weakness is in continuity and sector coupling. A biofuel sector requires repeated cycles of applied research associated with procurement and blending conditions. It also requires customary test methods and interlaboratory reliability. The quality and standards are active issues for the blending policy implementation shows the Energy Sector Synopsis Report (2024, Water and Energy Commission Secretariat). As increased public reporting, quality standards still being prepared for blending ethanol. This gap indicates a missing capability layer. For NAST, the Act does support a priority-based research role but the missing element is a visible biofuel pro-gramme line with protected resources and stable interfaces with fuel market actors.

5.4.2 Actor Coordination and Brokerage

Coordination is a key function of CRIB. In the case of the biofuels, coordination tasks are between the supply areas from agriculture, industrial production, blending of fuels, and retailing. Nepal has a segmented institutional landscape. NOC has control over import and distribution. Quality rules are developed by standards bodies. Sector agencies are responsible for programming renewable energy. Technical capabilities are held by universities and firms.

NAST has legal power to conduct coordinated programmes with domestic and foreign science and technology organisations (Government of Nepal, 1991). This provides a rather strong formal base for brokerage. The practical issue is whether or not NAST has operational routines to get these actors into alignment around a single programme logic for biofuels. In the current policy moment, the order of ethanol blending increases the demand for coordination and forces coordination on procurement, pricing, standards and testing (Radio Nepal, 2026a; Radio Nepal, 2026b).

A feasible ISB role for NAST would use its convening power to establish a standing biofuel working structure that includes NOC, standards agencies, and producers. That structure would manage the pipeline from research to testing to pilot blending, with clear responsibilities and a shared reporting routine.

5.4.3 Experimentation, piloting, and learning by doing

Experimentation is where many developing country biofuel plans fail. The gap is rarely the absence of pilot ideas. The gap is the absence of durable pilot platforms, shared facilities, and repeatable protocols for learning.

In Nepal, the emerging blending policy indicates that pilots will need to move from discussion to implementation. Public reporting indicates that implementation will require standards, minimum pricing work, and bid based selection (Radio Nepal, 2026b). Those steps imply that pilots will sit at the interface of policy and market.

In the Finland case, shared pilot facilities reduce entry barriers for firms and allow faster iteration. Nepal lacks an equivalent shared platform at scale for liquid biofuel testing and demonstration. This does not require copying the Finnish infrastructure model. It requires a smaller set of credible pilot nodes. A pilot node could be a blending trial coordinated with NOC depots and verified through accredited test protocols. NAST can support this by designing pilot protocols, hosting data, and validating results.

5.4.4 Legitimacy, standards, and verification

Legitimacy work is central for biofuels. It includes environmental legitimacy and user trust. It also includes the perception that procurement is fair and that product quality is consistent.

Nepal's standards regime is still strengthening in many product areas. In trade reporting, Nepal's standards body is described as participating in international standards and legal metrology systems, with steps taken to align with code of good practice procedures (WTO, 2025). This matters for biofuels. Fuel blending and fuel quality require reference standards and compliance pathways.

The ethanol blending order discussion shows that quality standards are now a central policy task, not an academic point (Radio Nepal, 2026b). This creates a direct opening

for a CRIB style function. NAST can fill a legitimacy role by supporting standards development through evidence, by building testing capacity in partnership with standards laboratories, and by publishing transparent results from pilots.

5.4.5 Resource mobilisation and risk reduction

Biofuel investment faces early stage risk. That risk comes from feedstock variability, uncertain policy continuity, and uncertainty about market uptake. Risk reduction instruments include co funded pilots, public procurement commitments, and credible quality assurance.

Nepal's policy signal is moving in a supportive direction through the blending order. Yet public reporting still indicates uncertainty about pricing, supplier selection, and commercial supply readiness (Radio Nepal, 2026b). This increases perceived risk for private producers.

NAST has legal authority to receive financial and technical assistance from national and international organisations for science and technology activity (Government of Nepal, 1991). That provision supports a resource mobilisation role, but only if NAST converts it into programme instruments that reduce early risk. This can include joint pilot funding, shared testing facilities, and formalised partnerships with NOC.

To consolidate the above functional assessment, Table 9 summarises how the CRIB lens maps onto the ISB relevant functions in Nepal's biofuel context, using NAST as the focal institution. The table aligns each function category with its practical meaning, the main evidence signals visible in the Nepal case, and the gap signals that indicate where system building interventions remain necessary. This synthesis is used as a bridge to the cross case discussion, because it makes the Finland Nepal comparison more explicit at the level of functions rather than only at the level of actors or policies (Howells, 2006; Bergek et al., 2008).

Table 9. CRIB and ISB function map for NAST in the Nepal biofuel context

Function category	What it means	Evidence signals in the Nepal case	Gap signals and design needs

Build capabilities	Applied research, skills, and infrastructure for technology development	Technical studies exist in Nepal on ethanol and biodiesel pathways (Khatiwada & Silveira, 2009; Timilsina & Tiwari, 2015)	Weak continuity and weak coupling to market operators. Needs a protected biofuel programme line and test method capability
Coordinate actors	Convening and brokerage across policy, research, and industry	NAST Act assigns coordination and advisory roles (Government of Nepal, 1991)	No stable biofuel coordination routine visible. Needs a standing coordination unit linking NOC, standards bodies, producers, and universities
Enable learning and diffusion	Pilots, demonstration, and knowledge circulation	Blending policy preparation is active and implies pilot activity (Radio Nepal, 2026b)	Limited shared pilot platforms for liquid fuels. Needs structured blending trials with verified results and shared access to data
Create legitimacy	Credibility, standards support, verification capacity	Quality standards and procurement rules are now central to policy discussion (Radio Nepal, 2026b)	Standards and testing capacity remain binding. Needs accredited testing links and transparent reporting to build user trust
Mobilise resources and reduce early risk	Co funded projects and instruments that reduce early stage risk	NAST can receive technical and financial support under its Act (Government of Nepal, 1991)	Private investment remains risky due to uncertain pricing and supply readiness. Needs co funded pilots, shared facilities, and procurement clarity

***Note**. Author synthesis derived from the CRIB function lens and Nepal policy and institutional documents (Government of Nepal, 1991; Radio Nepal, 2026a; Radio Nepal, 2026b) and sector reporting (Nepal Oil Corporation, n.d.; Water and Energy Commission Secretariat, 2024).*

Figure 6 visualises the same argument in a process view. It maps NAST's potential contribution across the biofuel innovation chain, from knowledge development to testing

and standards, then to piloting and market uptake. The purpose is to show where coordination and verification functions become binding under an ethanol blending policy, and where institutional interfaces remain weak. In Figure 6, the colours only distinguish function groups rather than levels of performance. This visual summary supports the functional interpretation in the next Section and helps keep the later cross case comparison anchored in system functions rather than organisational labels (Howells, 2006; Bergek et al., 2008).

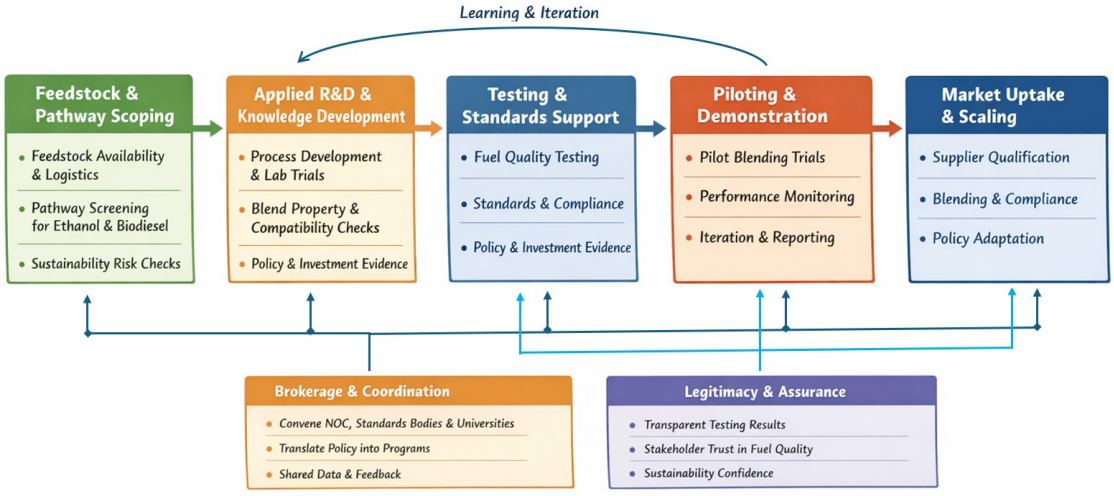

Figure 6. NAST functional map across the biofuel innovation chain
***Note**: The colours here only distinguish function groups rather than levels of performance*

5.5 Summary of Findings from Case 2

The Nepal case reinforces the thesis claim that biofuel sector development depends on system functions, not only on technical feasibility. Nepal's imported fuel exposure and the scale of petrol and diesel use create a persistent motivation to seek partial substitutes (Nepal Oil Corporation, n.d.; Water and Energy Commission Secretariat, 2024). The new ethanol blending policy signal increases that motivation and creates a concrete demand for standards and supplier readiness (Radio Nepal, 2026a; Radio Nepal, 2026b).

NAST has a legal mandate that aligns with several ISB functions. The Act assigns research, coordination, documentation, and technology transfer support roles (Government of Nepal, 1991). The gap is operational. Biofuels require a chain of testing, verification, pilot governance, and market facing legitimacy work that is not yet institutionalised in a stable way. The CRIB mapping shows that the largest missing capacities sit in standards linked

testing, shared pilot routines, and risk reduction instruments that make private supply investable. The case analysis suggests that the main constraint is not the absence of biomass resources or technical ideas in Nepal. The deeper problem is the difficulty of converting pilot-level activity into repeatable sector routines. These routines include testing, standard setting, procurement rules, and credible pathways for demonstration and investment, all of which are necessary if biofuel activity is to move from isolated experimentation to cumulative system development (Howells, 2006; Ockwell & Byrne, 2016). This analysis sets up the cross case translation. The next stage is to extract lessons from the Finland case at the level of functions and governance principles, then assess what is feasible in Nepal under institutional distance and absorptive capacity constraints (Cohen & Levinthal, 1990; Kostova, 1999; Rose, 1991).

6 Cross case analysis

This chapter synthesises the Finland and Nepal case evidence and develops the lesson drawing logic. It compares VTT and NAST as focal carriers of innovation system builder (ISB) functions, then translates the comparison into a feasible design agenda for Nepal's biofuel sector. The discussion follows the function first approach introduced earlier. It treats transferability as conditional on institutional distance and absorptive capacity (AC), rather than as a question of copying organisational form (Kostova, 1999; Cohen & Levinthal, 1990; Rose, 1991).

6.1 Cross case comparison framework

The cross case comparison is organised around three linked layers. The ***first layer*** is national innovation system (NIS) conditions. Finland shows higher policy continuity, deeper applied research infrastructure, and stable instruments that reduce early stage risk. Nepal shows fragmented mandates and thinner support infrastructure. These NIS conditions shape how easily sector routines can be stabilised (Lundvall, 2010; Edquist, 1997). The ***second layer*** is Triple Helix (TH) interaction quality. In Finland, collaboration is supported by mature intermediaries and shared platforms that reduce transaction costs. In Nepal, interaction exists but tends to be episodic and project based. This limits cumulative learning in a sector that depends on standards and infrastructure interfaces (Etzkowitz & Leydesdorff, 2000; Howells, 2006). The ***third layer*** is the organisational mechanism. In Finland, VTT performs a wide bundle of system functions, including piloting, testing, and credibility building. The presence of pilot scale infrastructure such as Bioruukki illustrates how experimentation is supported through shared facilities that help firms move from lab work to semi industrial learning cycles. In Nepal, NAST holds a broad legal mandate for science and technology development and coordination, but its biofuel relevant functions remain less institutionalised as sector routines (Government of Nepal, 1991).

A practical way to read the comparison is to treat VTT as a mature reference for CRIB functions and treat NAST as a candidate platform that can be redesigned to carry a narrower, sequenced set of CRIB functions in biofuels (Ockwell & Byrne, 2016).

6.2 Lesson drawing: what is transferable and what is not

From a system-building viewpoint, the core lesson is methodological. Nepal should not replicate Finnish institutional form. Nepal should replicate functions. Finland's model is useful as a functional benchmark. It shows which problems are solved, through what capabilities, and with what governance arrangements. Figure 2 summarises this lesson drawing logic as a functional sequence that supports feasible, functionally equivalent design in Nepal. This approach aligns with innovation system functions research, which treats knowledge development, experimentation, resource mobilisation, market formation, legitimation, and system wide learning as the processes that determine sector progress (Hekkert et al., 2007; Bergek et al., 2008).

The cross case discussion is organised around five propositions that are now evaluated against the Finland and Nepal evidence. P1 is that ISB effectiveness in biofuels depends on stable funding, sector specific capabilities, and industry coupled programme design rather than generic mandates. P2 is that policy volatility and fragmented mandates constrain ISB performance in developing contexts, which raises the value of convening power and coordination routines. P3 is that transferability is conditional on absorptive capacity, so functions travel more easily than institutional forms. P4 is that legitimacy building and sustainability governance are core functions that condition market formation and durability. P5 is that a CRIB oriented redesign of NAST requires mandate coherence, boundary spanning legitimacy, and capabilities in standards, testing, and demonstration (Cohen & Levinthal, 1990; Kostova, 1999; Rose, 1991; Ockwell & Byrne, 2016).

Finland and Nepal differ in industrial structure, public funding capacity, and the maturity of quality infrastructure. What can travel are functions, routines, and governance principles. What cannot travel intact are scale dependent features that rely on Finland's long accumulated industrial base and funding depth (Dolowitz & Marsh, 2000; Rose, 1991).

6.2.1 Transferable elements at the level of functions

Four transferable function-level elements stand out: coordination routines, shared piloting, standards and testing capacity, and operational legitimacy.

Finland illustrates that system building depends on repeated coordination embedded in programmes and facilities. Intermediary research treats this as a core role of innovation intermediaries, especially in sectors where complementarity is high and uncertainty is persistent (Howells, 2006). For Nepal, the lesson is that a biofuel working structure should be permanent and resourced, not an ad hoc committee.

VTT's piloting platform logic reduces firm risk and compresses learning time. Bioruukki is described as a pilot centre that allows customer organisations to develop and scale innovations under one roof. For Nepal, the transferable principle is not building an identical facility. It is creating credible pilot nodes with shared access and agreed protocols.

In regulated fuel markets, standardisation and measurement capacity shape adoption. Finland's biofuel policy instruments operate in a wider governance environment where compliance and verification capacity exists. Finland's distribution obligation has been revised, but the policy remains in force and continues to create a predictable compliance requirement for fuel suppliers. This reinforces the lesson that market signals require credible quality governance to be investable.

Biofuels remain contested due to land use and food trade offs. That debate becomes an implementation constraint when sustainability criteria are weak or non credible (Searchinger et al., 2008; Fargione et al., 2008). In practice, legitimacy is built through transparent measurement, traceability, and accountability routines.

6.2.2 Non transferable elements at the level of form

Three form-level elements are not directly transferable: public R&D scale, industrial pull, and quality-infrastructure depth. First VTT's portfolio reflects decades of cumulative investment. Nepal cannot replicate that scale quickly. A smaller capability building pathway is required. Second Finland's bioenergy trajectory is supported by industrial actors with deep process capabilities. Nepal's industrial base for liquid biofuels is narrower. This reduces the immediate demand side for advanced piloting, and it changes what an ISB can realistically deliver in early phases. Third Finland benefits from mature measurement and standardisation arrangements across sectors. Nepal's capacity is improving, but coverage and enforcement constraints remain binding in fuel markets.

6.3 Designing an ISB roadmap for Nepal's biofuel sector

The Nepal case evidence suggests that the binding constraint is not the absence of ideas. The constraint is the lack of stable system functions that turn ideas into routines. A realistic roadmap therefore needs sequencing. It also needs an institutional home that can coordinate across agencies and survive policy cycles.

The roadmap proposed here treats NAST as the anchor platform, but it assumes that delivery will be multi actor. NAST's legal mandate includes research promotion, coordination, and technology transfer support, which provides formal legitimacy for a CRIB oriented role. The question is how to translate that mandate into a narrow, measurable set of biofuel functions.

6.3.1 Phase 1: Develop the coordination core and a minimum viable standards pathway

The first phase is the building of a coordination spine and reduction of ambiguity. A standing biofuel coordination unit should be established within NAST, which will have a clear working interface to the fuel market operator and the standards authority. Its role would be practical. It should bring together the relevant actors, provide agendas, and keep common data and reporting routines. This fits intermediary theory which shows that brokerage works best when it is institutionalised and properly resourced rather than treated as ad hoc networking (Howells, 2006). In parallel, Nepal's shift to ethanol blending generates sharp quality assurance needs in the short-term. Public reporting suggests that active preparation is underway to put in place blending of up to 10 percent ethanol in petrol. Even if implementation is gradual, the signal grows the demand for testing protocols, rules on chain of custody and arrangements for dispute resolution. A minimum viable standards pathway can be developed through three deliverables. The first is a published blend specification and sampling protocol. The second is a set testing workflow with agreed laboratories and inter-laboratory check. The third one is the simple compliance documentation template used by suppliers and fuel market operator. These are artefacts of governance. They can start small. They are important because they promote predictable routines and minimize uncertainty for the suppliers and users.

6.3.2 Phase 2 - building pilot nodes and learning loops

The second phase of is learning by doing. It requires controlled pilots, docu-mented outcomes and structured feedback into standards and procurement rules. Finland's lesson is not the physical size of Bioruukki. It is the operating logic of shared piloting as a means for speeding up learning and mitigating risk at the early stages of investment because open access pilot facilities enable firms to test options and generate credible evidence to be used for making in-vestment decisions. Nepal can use the same logic using smaller pilot nodes connected to existing fuel depots and laboratories and supported by a noticeable protocol for performance monitoring and incident reporting. These pilots need to be designed for traceability from the beginning. Feedstock origin and ethanol quality should be tracked, blend prepa-ration should be documented and compatibility tracked in a bounded fleet or controlled user set. The pilot should also have some simple stop rules that specify when the blending is stopped and how to adjust. With these elements in place, pilots are turned into system-level learning assets rather than one off demonstration. This fits with the concept of experimentation and system-wide learning as key functions in innovation system emergence and the role of intermediaries in structuring these learning processes (Hekkert et al., 2007; Bergek et al., 2008).

6.3.3 Phase 3 Market formation instruments and supplier development

The third phase takes the center of gravity away from controlled trials and brings it to the field of regular market operation, in which the binding tasks are replaced by supplier qualification and procurement readiness and continuous compliance monitoring. Policy instruments such as blending mandates can create demand, but only market formation is stable once the compliance logic is predictable and enforceable. The example of Finland's experience with a statutory distribution obligation serves as an illustration of this point, as the instrument remains a market rule even when targets are updated, which helps to maintain planning certainty for obligated actors and suppliers (International Energy Agency, 2024). For Nepal, the design challenge is therefore to link any blending policy with credible enforcement capacity, and avoid a nominal mandate that precedes supply readiness. Supplier development should be supported through an ISB led capability

programme which includes provision of targeted support for production quality management, support of certification and documentation routines and development of structured engagement with finance actors using verified pilot evidence to reduce early stage risk. This sequencing is consistent with the CRIB argument that technology transfer and uptake is enhanced by building domestic innovation capability in conjunction with adoption incentives and credible governance mechanisms (Ockwell & Byrne, 2016).

Actor-specific implications are consolidated in Chapter 7 so that the discussion chapter remains focused on cross-case interpretation, transferability, and roadmap design.

7 Conclusions and recommendations

This chapter concludes the thesis by answering the research questions, declaring the major contributions, and proposing actor-specific recommendations in a feasible order. The structure is in accordance with the approved outline.

7.1 Answers to the Research Questions

This thesis has addressed the central question of how a developing country can build an effective innovation-system builder for the biofuel sector by learning from a developed-country model. The answer that emerges from the Finland-to-Nepal comparison is that effective lesson-drawing must proceed through functional adaptation rather than organisational copying. The Finnish case shows that biofuel system-building depends on a bundle of stable functions: coordination routines, applied research capacity, shared piloting and testing infrastructure, standards-related credibility, and market-facing verification. These functions are carried by durable institutions and are strengthened by continuity in policy, funding, and cross-sector collaboration. The Nepal case shows that policy ambition and technical knowledge are not enough on their own. What remains weak are the interfaces that connect research, testing, pilots, standards, and market formation. For that reason, the practical challenge in Nepal is not to reproduce the Finnish institutional form, but to build a smaller and feasible set of system functions in a phased way that fits local constraints.

The first sub-question concerned the functions, capabilities, and governance arrangements that enable Finland's innovation-system builders, with emphasis on VTT, to support biofuel innovation. The findings show that VTT performs a strong system-building role because it combines applied research, industry-facing programme work, open-access pilot and testing environments, and standards-related credibility within a stable governance and funding structure. These elements matter in combination. Shared infrastructure supports experimentation. Repeated cooperation routines connect universities, industry, and government. Measurement and verification capacity strengthen legitimacy in a politically sensitive field. Taken together, these features make Finland a useful reference case at the level of functions rather than at the level of institutional form.

The second sub-question examined the institutional and capability gaps that limit Nepal's potential innovation-system builder, with emphasis on NAST, and the lessons that remain transferable under Nepal's conditions. The analysis shows that Nepal has a basic knowledge base, policy interest, and resource potential, but lacks continuity in programme delivery, strong testing and standards capacity, and stable routines linking pilots to market development. NAST has a legal basis that supports coordination and technology-oriented work, yet its biofuel-relevant role remains largely potential rather than consolidated. The lessons that are transferable are therefore the logic of standing coordination, transparent verification, pilot-based learning, and phased market formation. What is not directly transferable is the scale of Finnish public research infrastructure, industrial depth, and institutional maturity. Functional equivalence, rather than replication, is therefore the realistic design target for Nepal.

7.2 Key contributions

7.2.1 Theoretical contribution

This thesis makes three theoretical contributions. First, it sharpens the concept of the innovation-system builder by treating it as a carrier of observable system functions rather than as a descriptive label attached to an organisation. The analysis shows that coordination, experimentation support, standards capacity, resource mobilisation, and legitimacy work can be examined as discrete but connected functions within a sectoral innovation system.

Second, the thesis clarifies lesson-drawing under constraint. The Finland-to-Nepal comparison shows that institutional form travels poorly across contexts, but functional design principles travel more effectively when they are filtered through institutional distance and absorptive capacity. This turns policy transfer from a general warning against copying into a more precise explanation of what can be transferred, what must be adapted, and what depends on local capability-building.

Third, the thesis applies the CRIB lens to a sector-specific design problem. In biofuels, capability-building and legitimacy formation are not secondary issues. They are core system-building functions that shape whether market formation becomes durable. In this

sense, the thesis links sustainability-transitions research, innovation-systems theory, and climate-relevant institution-building in a more operational way.

7.2.2 Policy contribution

The thesis discusses why mixing mandates and strategy statements will not replace quality infrastructure and routines for coordination. It considers standards, testing, and traceability as policy instruments in their own right because they influence credibility and in-vestment risk and public acceptance. This helps explain the fact that many developing country biofuel efforts have been stuck in the project stage, even if the potential for feedstocks exists (Malerba, 2002; Arocena & Sutz, 2010).

7.2.3 Practical contribution

The thesis is provided a phased design logic for Nepal. It is a translation of the Finland benchmark into feasible steps given the institutional and resource constraints of Nepal. It identifies early deliverables that do not require large capital outlays such as standing coordination unit, minimum viable blend specifications and pilot protocols with transparent reporting. It then connects these earliest deliverables to medium-term building capability in testing networks and pilot nodes. This is providing a practical pathway for NAST to function as a CRIB-like platform in biofuels, although without reflecting the breadth of VTT's (Ockwell & Byrne, 2016; Howells, 2006).

7.3 Recommendations

The recommendations are organised by actor and ordered by feasibility. Early actions focus on coordination and verification. Medium term actions develop pilot capacity and learning routines. Subsequent actions include the scaling up of market formation instruments after the supply readiness and compliance capacity is established.

7.3.1 Government of Nepal

The first is mandate coherence in energy, industry, agriculture and standards functions. A single implementation logic is needed for blending, testing, compliance and dispute handling. Without this, agencies optimise locally and the system drifts (Edquist, 1997;

Bergek et al., 2008). The second priority is to consider quality infra-structure as an enabling investment. A blend decision leads to immediate need in sampling protocols and test methods as well as in the chain of custody documentation. These governance artefacts lower risk for the users and suppliers. The third priority is to phase market formation instruments. Blending targets should be based on tracking supply readiness and testing capacity. Premature mandates raise the risks of performance quarrel and policy reversal. This staged approach aligns with evidence in the literature about inappropriate transfer in which instruments fail due to the lack of institutional preconditions (Dolowitz & Marsh, 2000; Rose, 1991).

7.3.2 NAST leadership and governance

NAST requires a narrow mission line for biofuels with clear deliverables and protected continuity. Broad mandates water down effort unless they are converted into sector routines. Early deliverables should include a standing coordination mechanism, bringing together the fuel market operator, standards bodies, universities and potential producers, supported by a common reporting routine, and a single data repository. This is brokerage as a system function not a networking event (Howells, 2006). The next deliverable is a minimum viable verification pathway linking testing laboratories, supporting inter-laboratory checks and publishing pilot results in a format that facilitates learning and accountability. Transparent verification preserves legitimacy in a domain defined by sustainability debates and trust barriers (Searchinger et al., 2008; Fargione et al., 2008). The medium-term step is to sponsor pilot nodes on the basis of standard protocols, so pilots produce evidence that is similar and real learning loops. This leads to the development of absorptive capacity through the repetition of practice in measurement, reporting, and adaptation (Cohen & Levinthal, 1990; Zahra & George, 2002).

7.3.3 Private sector and Financiers

Firms and financiers need rules that are predictable and credible. The first requirement is a supplier qualification pathway that is transparent and linked to quality criteria that can be measured. This is done to reduce uncertainty in the entry and ensure the legitimacy of the procurement. The second requirement is a pilot to contract bridge. Pilot

participation should provide for the generation of bankable signals such as verified performance data, traceability, and a clear compliance workflow. This makes experimentation investable learning. The third requirement is sharing the risk. Early-stage biofuel supply is challenged by feedstock variability and policy risk, so co-funded pilots and offtake structures can reduce cost of capital. These mechanisms are consistent with the arguments that innovation systems make about the role of resource mobilisation and legitimation in the emergence of a sector as much as technical feasibility (Hekkert et al., 2007; Bergek et al., 2008).

7.3.4 Universities, training institutions

Universities should match applied research and training with the binding constraints in the biofuel chain. Early work should put emphasis on test methods, quality management, compatibility of blending and sustainability measurement because these capacities are at the centre of legitimacy and compliance. Training pipelines should concentrate on laboratory competence, standard operating procedures, and data reporting routines. This creates a strengthening of the absorptive capacity in a direct manner and enhances the capacity to assimilate external knowledge and operate local problem-solving cycles (Cohen & Levinthal, 1990). Universities also need to have structured interfaces with NAST and industry. Short applied projects in connection with pilots can help to build trust and to reduce the distance between the academic work and sec-tor needs (Etzkowitz & Leydesdorff, 2000; Howells, 2006).

7.4 Limitations and future research

This thesis is mostly based on documentary evidence. This is supportive of traceable comparison, but does no justice to the role of informal bargaining, political constraints and tacit practices of coordination that rarely make it to official texts (Bowen, 2009; Yin, 2018). The two-cases design adds a degree of depth and clarity of the mechanisms, but loses statistical generalisation. The value is in analytic transfer through functions and conditions and not universal claims (Flyvbjerg, 2004). The Nepal case is also indicative of some typical asymmetries in data, which can lead to a bias towards formal mandates rather than everyday capability in terms of visibility.

Future research can be extended in four directions. The first direction is one of comparative expansion. Additional cases such as Brazil, India, Sweden, or Thailand could be used to test whether the function first ISB model travels across different bases of feedstock, industrial structures, and traditions of regulation. This would make the distinction clear between transferable system functions and path-dependent institutional features (Malerba, 2002; and Dolowitz & Marsh, 2000).

The second direction is primary fieldwork. Interviews with NAST, Nepal Oil Corporation, standards bodies, producers, transport regulators and financiers would make it possible to trace how coordination routines actually work, where mandates collide, how pilot evidence is used and why some routines stabilise while others stall. This would overcome the limitations of document-based evidence and make the analysis more sensitive to informal practice.

The third direction is implementation research. The phased roadmap as proposed in this thesis may be investigated with process-tracing, action research or longitudinal case designs following the development of coordination units, pilot nodes and verification pathways through time. Such work could evaluate whether these interventions enhance learning speed, credibility of compliance and investor confidence in the practice.

The fourth direction is the development of measurement. Future studies should construct sector-specific indicators for performance of ISB in late industrialising settings. Useful indicators could be pilot repetition, pilot to procurement time, laboratory accreditation status, supplier qualification time, traceability quality, and stakeholder trust in testing and compliance systems. This would enable the evaluation of CRIB-style institution building to occur not only at a conceptual level, but also at an empirical level across countries and through time (Ockwell & Byrne, 2016; Hekkert et al., 2007).

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